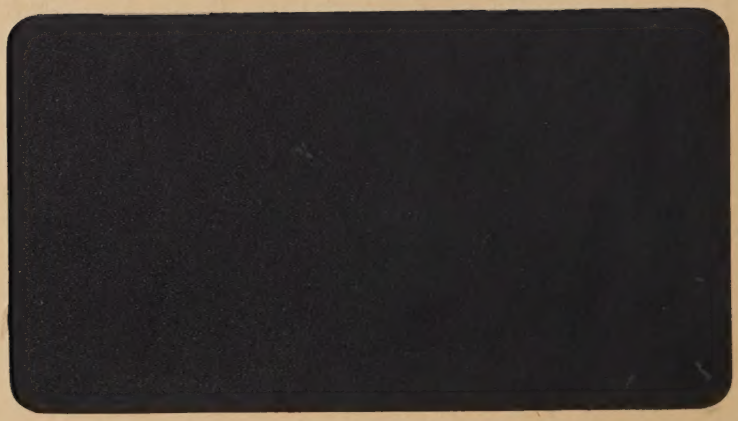
INSTRUCTION MANUAL

GENERAL RADIO



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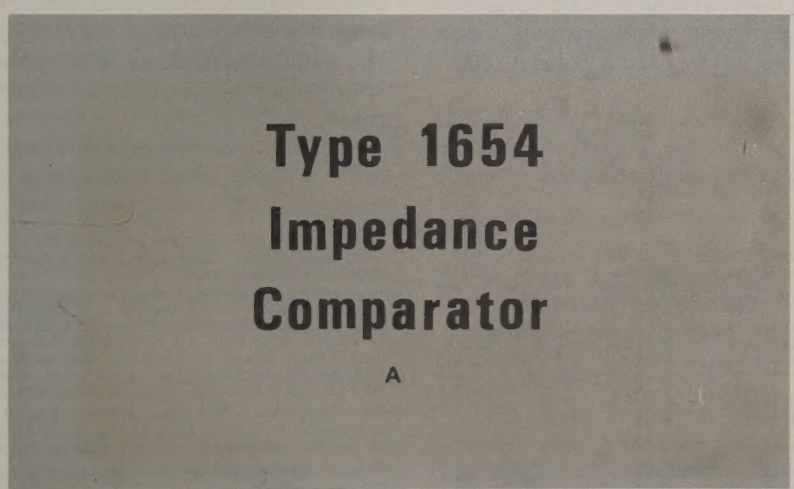
WARRANTY

We warrant that each new instrument manufactured and sold by us is free from defects in material and workmanship and that, properly used, it will perform in full accordance with applicable specifications for a period of two years after original shipment. Any instrument or component that is found within the two-year period not to meet these standards after examination by our factory, District Office, or authorized repair agency personnel will be repaired or, at our option, replaced without charge, except for tubes or batteries that have given normal service.



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West Concord, Massachusetts, U.S.A. 01781
Form 1654-0100-A
June 1969
ID-0100

Condensed Operating Instructions

CAUTION
DO NOT APPLY CHARGED CAPACITORS

GENERAL PROCEDURE.

a. Turn the POWER switch on and wait at least 30 seconds for the instrument to warm up.

b. Select the operating frequency and check with the table below for impedance limits.

c. Connect the standard and unknown components to the appropriate terminals, using either direct connections or the Type 1680-P1 Test Fixture for the unknown.

d. To check the zeros on the meters, turn the INPUT switch to the ZERO position. Turn both deviation FULL SCALE ranges to the most sensitive range. Adjust both ZERO controls for zero meter readings.

e. To calibrate the ΔZ meter, set the MAGNITUDE DIFFERENCE % switch to 1. Set the INPUT switch to CAL 1%, and adjust the CAL 1% control to give a 1% full-scale indication.

f. Select the desired range for the ΔZ and $\Delta\theta$ meters as well as the test voltage. Test-voltage and measurement ranges are related and their panel switches interlocked to reflect this relationship.

g. Select GUARDED or UNGUARDED operation. GUARDED operation is preferred for shielded components or for remote and high-impedance measurements. Capacitance to the shield is reduced by a factor of about 1000, if the shield is guarded.

h. Select type of measurement: RESISTANCE/INDUCTANCE or CAPACITANCE. For certain inductance measurements, the guarded operation may cause self-excitation of the circuit as indicated by the OFF-SCALE lamp being lit. The UNGUARDED position should be used if such oscillations occur.

Phase-angle difference and magnitude difference between the standard and unknown are indicated by the $\Delta\theta$ and ΔZ meters respectively, and by analog voltage outputs from the rear panel.

EXTERNAL OR REMOTE START.

Remote start can be achieved with the use of the 1680-P1 Component Test Fixture or by external contact closure. Insert the phone jack on the test fixture into the START socket on the rear panel and, with the START switch on EXT, momentarily closing the built-in switch on the fixture will initiate measurement.

ACCURACY.

The accuracy of the 1654 is 3% of full scale, i.e., for the ±0.1% magnitude-difference scale, accuracy is 0.003% of the measured impedance magnitude.

The instrument may produce small errors above the specified 3% when the meters are used at opposite range extremes, i.e., when one meter is near full scale on its least sensitive range and the other reading on its most sensitive range. The error occurs on the most sensitive meter. When very small differences are to be accurately measured, the other meter should be balanced to better than 1% (or 0.01 radian).

For measurement outside the ranges listed above, refer to the correction equations and tables in Section 3.

specifications

Frequencies: Internal only 100 Hz, 1, 10, and 100 kHz, ±1%.
Ranges: 0.1% to 30% full-scale impedance difference; 0.001 to 0.3 radians full-scale phase-angle difference. Available ranges depend on test voltage selected as shown in the following table.

Test Voltage	Impedance Difference Full-scale Range — %						Phase-Angle Difference Full-scale Range — Radian					
	0.1	0.3	1	3	10	30	0.001	0.003	0.01	0.03	0.1	0.3
0.3 V			x	x	x	x			x	x	x	x
1 V		x	x	x	x			x	x	x	x	
3 V	x	x	x	x			x	x	x	x		

Impedance Ranges (0.3-V test voltage*):

	Resistance	Capacitance	Inductance
Full useful range	2Ω — 20 MΩ	50 pF** — 1000 μF	20 μH — 1000 H
at 100 Hz	2Ω — 20 MΩ	1000 pF — 1000 μF	5 mH — 1000 H
at 1 kHz	2Ω — 2 MΩ	50 pF** — 100 μF	500 μH — 100 H
at 10 kHz	2Ω — 200 kΩ	50 pF** — 10 μF	50 μH — 1 H
at 100 kHz	10Ω — 10 kΩ	50 pF** — 0.1 μF	20 μH — 10 mH

*Low R and L limits are increased and upper C limit decreased by 10:1 for 1-V test voltage and by 100:1 for 3-V.
**To 0.1 pF by substitution method.

Resolution: Meter, 0.003% and 0.00003 radian. Analog-voltage output, 0.001% and 0.00001 radian.
Accuracy: 3% of full scale.
Voltage Across Standard and Unknown: 0.3, 1, or 3 V selected by front-panel control. Test voltage of 2 V (with 0.6 and 6 V) can be obtained on special order.
Analog-Voltage Outputs: Voltages proportional to meter deflections at two rear-panel connectors: ±10 V full scale behind < 10Ω for 1782 Analog Limit Comparator; ±3 V or ±10 V (depending on range) full scale behind 2 kΩ for DVM, A-D converter or other use.
Test Speed: About 1 component per second with meter, max. With analog output voltage, about 4 components per second, except about 1 component per second at 100 Hz.
Power Required: 105 to 125 or 210 to 250 V, 50 to 60 Hz, 15 W.
Accessories Available: 1782 Analog Limit Comparator; GR decade boxes and standards of resistance, capacitance, inductance.
Accessories Supplied: Multiple contact connector, and power cord
Mounting: Bench model (in metal cabinet) or rack model.
Dimensions (weight x height x depth): Bench, 19½ x 8¾ x 15 in. (495 x 225 x 385 mm); rack, 19 x 7 x 13½ in. (485 x 180 x 345 mm).
Net Weight: Bench, 40 lb (19 kg); rack, 25 lb (12 kg).
Shipping Weight: Bench, 60 lb (28 kg); rack, 40 lb (19 kg).

Catalog Number	Description
	1654 Impedance Comparator
1654-9700	Bench Model
1654-9701	Rack Model

Introduction—Section 1

1.1 PURPOSE 1-1
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1.1 PURPOSE.

The 1654 Impedance Comparator indicates on large panel meters, and by analog output voltages, the difference in magnitude and phase angle between two external impedances, usually a standard and an unknown. These measurements are made rapidly and easily because no bridge-balancing operation is necessary. Wide ranges of impedance, resistance, capacitance, and inductance can be compared.

Because the 1654 is a transformer bridge, its accuracy is little affected by loading or by stray impedance. The precision possible when precise impedance standards are used, results in a system that can replace many intricate measurement setups in the laboratory and simplify most measurement procedures.

With an adjustable standard, the 1654 can be brought to a null, thus allowing for determination of transfer impedances of three-terminal networks. When the comparator is nulled, impedance shunting of the detector does not affect the balance, and the effect of impedance shunting the ratio arms is usually negligible due to the tight coupling of these arms.

Because the impedance-difference information is provided continuously, the measurement of changes in impedance due to environmental changes is greatly simplified. With a suitable analog recorder, such as the GR 1522, a record of the data can be easily made.

The combination of measurement speed, wide range, and high accuracy make the 1654 particularly useful for manual, semi-or fully-automatic selection and sorting applications, as well as intricate laboratory measurements.

Some typical uses are: rapid sorting and matching of precision components and networks, measuring the effects of time and environment on components, testing of the tracking of ganged potentiometers and variable capacitors, and studying the frequency dependence of components. Comparison of quantities usually requiring laboratory techniques are easily made, such as: small impedance differences, D of low-loss dielectric materials, D of inductors, Q or phase angle of wire-wound resistors and potentiometers, balance of transformer windings, semiconductor capacitances, and capacitance drift with temperature.

1.2 DESCRIPTION.

The instrument is basically a self-contained, bridge-measurement system consisting of a signal source, a bridge network, and a detecting circuit. The bridge network consists of the two external impedances to be compared and two highly precise unity ratio arms. Because of the inherent accuracy of the bridge, the measurement accuracy depends largely on the precision of the external standard.

Because the 1654 measures differences to an accuracy of 3% of full scale, the measurement accuracy and resolution as a percent of the total impedance are considerably better. The detector sensitivity permits measurements to

0.003% and 0.00003 radian, an order-of-magnitude more accurate than that of most precision impedance bridges.

The bridge circuit is not adjusted for a balance; instead, the unbalance voltage is measured to give the required impedance-difference information. The detector is phase sensitive and it selects those vector components of the unbalance voltage that are proportional to the impedance-magnitude difference in percent, as well as the phase-angle difference.

The metering circuit and the analog output voltage for the magnitude channel of the 1654 have been linearized to ensure accurate readings without correction for up to 30% impedance differences. Solid-state circuits are used in the 1654 so that drift of the meter zero is negligible, thus permitting more certain accuracy and fewer interruptions for readjustment.

The combination of four fixed frequencies from 100 Hz to 100 kHz, with a wide impedance range and several difference ranges, results in a flexible and extremely versatile impedance comparator.

The GR 1782 Analog Limit Comparator is available as an accessory for increasing the speed at which the 1654 operates when used for sorting applications (see Figure 1-1).

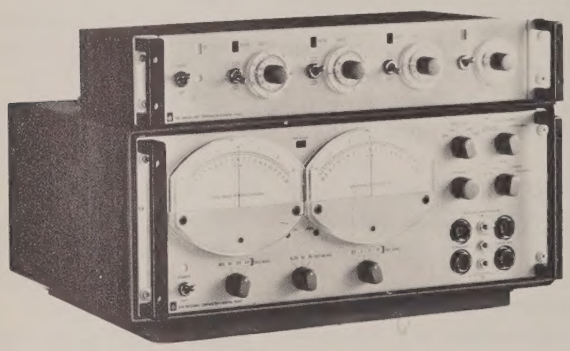


Figure 1-1. Typical 1654/1782 sorting system.

1.3 CONTROLS, CONNECTORS, AND INDICATORS.

The controls, connectors, and indicators described in Table 1-1 are located on the front panel of the 1654 Impedance Comparator (see Figure 1-2):

The contols and connectors described in Table 1-2 are located on the rear panel of the 1654 (see Figure 1-3).

1.4 ACCESSORIES SUPPLIED.

Accessories normally supplied with the 1654 Impedance Comparator are listed in Table 1-3.

1.5 ACCESSORIES AVAILABLE.

Table 1-4 lists accessories that are available for use with the 1654 comparator.

A variety of GR patch cords and adaptors are also available for the use with the 1654; refer to Table 1-5.

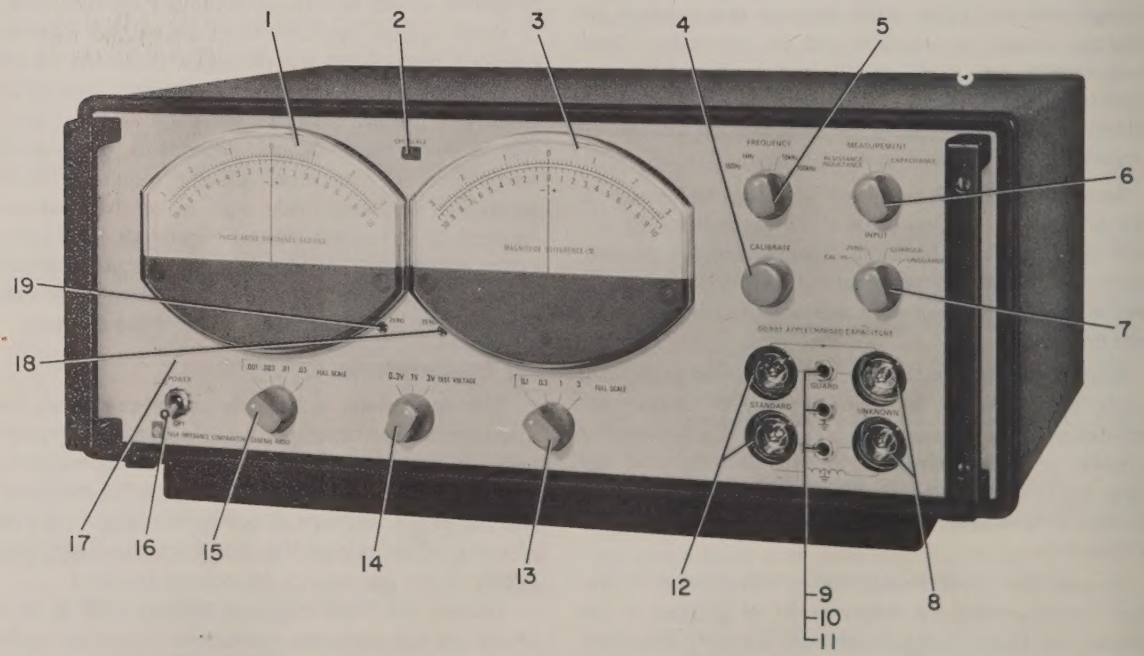


Figure 1-2. Controls, connectors, and indicators on the front panel of the 1654 comparator (refer to Table 1-1).

TABLE 1-1

FRONT-PANEL CONTROLS, CONNECTORS, AND INDICATORS

Fig. 1-2 Reference	*Name*	*Description*	*Function*
1	PHASE ANGLE DIFFERENCE-RADIANS	Meter with zero adjust (screwdriver adjustment) in center of lower panel (19)	Indicates phase-angle difference; a + reading indicates that the unknown has a larger phase angle than the standard, where θ is positive in the ccw direction on the conventional complex-impedance plane. If D_s and D_x (or Q_s and Q_x)are both $\leqslant 0.1$ and $\Delta Z \leqslant 10\%$, $\Delta\theta$ can be interpreted directly as ΔD or ΔQ with negligible error.
2	OFF SCALE	Incandescent lamp-operated indicator	Lights when bridge unbalance exceeds about 80% for 0.3-V test voltage, 20% for 1-V test voltage, and 6% for 3-V test voltage.
3	MAGNITUDE DIFFERENCE-%	Meter with zero adjust (screwdriver adjustment) in center of lower panel (18)	Indicates magnitude difference; a + reading indicates that the unknown has a higher impedance than the standard.
4	CALIBRATE	Potentiometer, continuous knob adjustment	Used to calibrate the instrument for 1% (full scale) with the INPUT switch set at CAL 1% and the MAGNITUDE DIFFERENCE/FULL SCALE control (13) set at 1.
5	FREQUENCY	Rotary switch, four-position	Provides selection of four measurement frequencies: 100 Hz, 1 kHz, 10 kHz, and 100 kHz.
6	MEASUREMENT	Rotary switch, two-position	Provides selection of RESISTANCE/INDUCTANCE or CAPACITANCE measurement.
7	INPUT	Rotary switch, four-position	Provides choice of four operations: CAL 1% - provides 1% unbalance voltage to input. ZERO - shorts input to ground, thus permitting both channels to be zeroed. GUARDED - The outer conductors of the upper GR874 connector pair are driven at nearly the same potential as the inner conductors. UNGUARDED - the outer conductors of the upper GR874 connector pair are grounded.
8	UNKNOWN	GR874 locking connectors, a pair	For connection of the unknown impedance to the bridge circuit.

TABLE 1-1 (cont)

FRONT-PANEL CONTROLS, CONNECTORS, AND INDICATORS

Fig. 1-2 Reference	*Name*	*Description*	*Function*
9	GUARD	Jack, guard (accepts banana plug)	Guard voltage available at this jack when the INPUT control is switched to GUARDED.
10	——	Jack, ground (accepts banana plug)	Chassis ground.
11	——	Jack, floating (accepts banana plug)	Means of connecting to guard or ground when measuring high impedances.
12	STANDARD	GR874 locking connectors, a pair	For connection of the impedance standard to the bridge circuit.
13	0.1, 0.3, 1, 3, 10, 30 FULL SCALE	Rotary switch, four-position	Selects deviation range to be read on MAGNITUDE DIFFERENCE-% meter.
14	0.3 V, 1V, 3V TEST VOLTAGE	Rotary switch, three-position	Provides selection of test voltages.
15	.001, .003, .01, .03 0.1, 0.3 FULL SCALE	Rotary switch, four position	Selects deviation range to be read on PHASE ANGLE DIFFERENCE meter.
16	POWER/OFF	Toggle switch, two-position	Applies or interrupts line-voltage supply to the instrument.
17	POWER	Incandescent lamp	Lights when power is applied to the instrument
18	ZERO	Potentiometer, continuous screwdriver adjustment	Means of adjusting meter zero of MAGNITUDE DIFFERENCE channel when INPUT control is set at ZERO.
19	ZERO	Potentiometer, continuous screwdriver adjustment	Means of adjusting meter zero of PHASE ANGLE DIFFERENCE channel when INPUT control is set at ZERO.

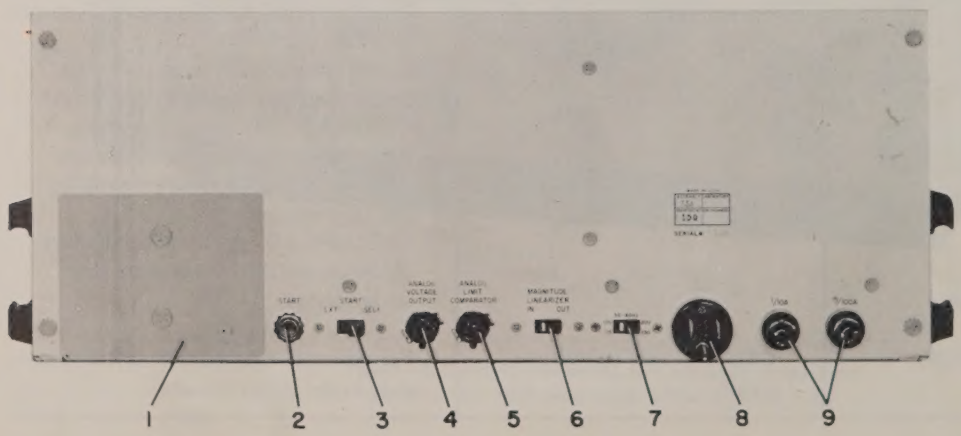


Figure 1-3. Controls and connectors on the rear panel of the 1654 comparator (refer to Table 1-2).

TABLE 1-2
REAR-PANEL CONTROLS AND CONNECTORS

Fig. 1-3 Reference	*Name*	*Description*	*Function*
1	STANDARD/UNKNOWN	Connector cover plate	Covers opening for STANDARD and UNKNOWN jacks and GR874 connectors when connection is made on other panel. Example; cover used on rear panel when connectors are located on front panel.
2	START	Phone jack, two-terminal	A momentary short between phone-jack terminals starts measurement when START switch (3) is set at EXT. For connection to remote-start unit, such as the 1680-P1 Test Fixture.
3	START EXT/SELF	Slide switch, two position	Selects either external start by contact closure or self start for automatic indication as soon as the unknown is connected to the UN-KNOWN terminals.
4	ANALOG VOLTAGE OUTPUT	Socket, five-pin	Connection to output voltages that are proportional to meter deflections, ±3-V or ±10-V full scale. For connection to digital voltmeter or recorder.
5	ANALOG LIMIT COMPARATOR	Socket, seven-pin	Connection to output voltages that are proportional to meter deflections, ±10-V full scale. For connection to 1782 Analog Limit Comparator.
6	MAGNITUDE LINEARIZER IN/OUT	Slide switch, two-position	Switches, in or out, the compensation network in the magnitude channel for nonlinearity of the bridge. In normal operation, the switch should be set to IN.
7	50-60 Hz	Slide switch, two-position	Selects 115-V or 230-V, 50-60 Hz operation.
8	—	Power plug, three-pin	Power-line connector, accepts power cord supplied.
9	—	Fuse, Slo-Blo, 0.15 A for 115-V operation, 0.1 A for 230-V operation	Over-load and short-circuit protection,

TABLE 1-3
1654 ACCESSORIES SUPPLIED

Quantity	*Description*	*Part Number*
1	Hardware Set, for installation of rack-mount instrument	4174-2000
1	Power Cable, 3-wire, 7 foot, for connecting instrument to power source	4200-9622
1	Multiple-Contact Connector, 5-contact, for connecting DVM, recorder, etc. to ANALOG VOLTAGE OUTPUT socket on rear panel	4220-5401

1.6 DEFINITIONS AND ABBREVIATIONS.

A complex impedance may be written in polar or Cartesian form:

$$Z = |Z|e^{j\theta} = R + jX$$

where Z = complex impedance
|Z| = magnitude of impedance
θ = phase angle of impedance
R = Real part of impedance
X = imaginary part of impedance or equivalent series reactance

Relationships between the two forms are:

$$|Z| = \sqrt{R^2 + X^2} \qquad R = |Z| \cos\theta$$

$$\theta = \tan^{-1} X/R \qquad X = |Z| \sin\theta$$

Likewse, a complex admittance can be written in two forms:

$$Y = |Y| e^{j\theta} = G + jB$$

where Y = complex admittance
|Y| = magnitude of admittance
ϕ = phase angle of admittance
G = real part of admittance or equivalent parallel conductance
B = imaginary part of admittance or equivalent parallel susceptance

TABLE 1-4
ACCESSORIES AVAILABLE

Name	*GR Type*	*Description*
Analog Limit Comparator	1782	Increases the speed of the 1654 for use in sorting applications. The 1782 compares the analog-voltage output of the 1654 against high and low limits and displays GO or NO GO lights for manual sorting. Models with optional relay contacts are available for automatic sorting.
Test Fixture	1680-P1	Facilitates rapid connection of unknown capacitors to the 1654 for manual sorting.
Dielectric Sample Holder	1690-A	Holder for convenient measurement of dielectric constant, dissipation factor, and volume resistivity of dielectric materials.
Standard Capacitors	1422	Variable, two- or three-terminal standard. The 1422 series of standards cover a range of 0.005 pf to 1150 pF.
Decade Capacitors	1423 1424 1425	Two- or three-terminal standards. 1423: 100 pF to 1.111 μF in 100 pF steps 1424: 10 μF in 1 μF steps 1425: 100 μF in 10 μF steps
Decade Inductor	1491	Two- or three-terminal standard. The 1491 series covers a range of 0.0001 H to 11.111 H.
	1440	Fixed, two-terminal standard. The 1440 series cover a range of 1 Ω to 1 MΩ.
Standard Resistors	1433	Variable, two- or three-terminal decade box. The 1433 series cover a range of 0.01 Ω to + 11MΩ.
Coupling Probe	874-MB	Adaptor consisting of a binding post mounted on an 874 coaxial connector
Adaptor Plate	1654-9600	Permits connection of unknowns with 3/4 in. lead spacings

The relationships between the two forms become:

$$|Y| = \sqrt{G^2 + B^2} \qquad G = |Y| \cos \phi$$

$$\phi = \tan^{-1} \frac{B}{G} \qquad B = |Y| \sin \phi$$

Relationships between the impedance and admittance are:

$$Y = \frac{1}{Z} \qquad |Y| e^{j\phi} = \frac{1}{|Z| e^{j\theta}}; \; |Y| = \frac{1}{|Z|}$$

$$\phi = -\theta \qquad \frac{B}{G} = -\frac{X}{R}$$

The MAGNITUDE DIFFERENCE meter, which will be referred to as the ΔZ meter, reads:

$$\frac{\frac{|Z_x| - |Z_s|}{|Z_x| + |Z_s|}}{2} = -\frac{\frac{|Y_x| - |Y_s|}{|Y_x| + |Y_s|}}{2}$$

where the subscripts x and s refer to the unknown and standard components. These expressions give the difference in impedance or admittance magnitude as a percent of the average of the magnitudes of the standard and unknown. If the percent difference is small, these expressions are equal to

$$\frac{|Z_x| - |Z_s|}{|Z_s|} \text{ and } -\frac{|Y_x| - |Y_s|}{|Y_s|}$$

with negligible error. (Since it is desirable to indicate the magnitude difference as a percent of the standard, the larger deviations have been linearized to compensate for the usual nonlinearity of the bridge output.)

These expressions will be referred to as $\frac{\Delta|Z|}{|Z|}$ and $\frac{\Delta|Y|}{|Y|}$ or, more simply, ΔZ and ΔY. A positive reading, therefore, indicates that the unknown is a larger impedance or a smaller admittance.

If pure elements are measured (R, L, or C), the ΔZ indication can be interpreted as a percent difference in resistance or reactance. The reactance difference in percent is equal to the inductance or capacitance difference in percent.

If the compared components are not pure, an error may result in interpreting the ΔZ reading as a ΔR, ΔL, or ΔC if the angle of the standard or unknown is over 0.01 radian; that is, if D (for inductors or capacitors) or Q (for resistors) is greater than 0.01. (Refer to paragraph 3.15.)

The PHASE ANGLE DIFFERENCE meter, which will be referred to as the $\Delta\theta$ meter, reads $\theta_x - \theta_s = -(\phi_x - \phi_s)$ in radians.

The phase angle, θ, is taken as positive in the counterclockwise direction on the complex inpedance plane. (See Figure 1-4.) Therefore, a positive $\Delta\theta$ indicates that the unknown is more inductive (or less capacitive) than the standard. Thus the reactance is positive if inductive ($+j\omega L$) and negative if capacitive ($-j\frac{1}{\omega C}$).

If relatively pure elements (C, R, or L) are measured (D or Q less than 0.1 or larger than 10), $\Delta\theta$ can be interpreted as a D or Q difference with negligible error. The instrument indicates whichever quantity is less than 0.1.

For inductors and resistors, we will define

$$Q = \frac{X}{R} = -\frac{B}{G} \qquad D = \frac{1}{Q} = \frac{R}{X} = -\frac{G}{B}$$

For capacitors, we will define

$$D = -\frac{R}{X} = \frac{G}{B}$$

(The minus sign is necessary to make the D of capacitance be positive, since X_c is negative.)

Figure 1-5 defines D and Q in terms of series or parallel elements.

Table 3-4 should be of help in determining the correct sign for the various measurements. However, it is usually simple enough to determine the correct sign by remembering that:

1. A positive ΔZ indicates that the component on the unknown terminals is the larger impedance.

2. A positive $\Delta\theta$ indicates that the unknown has the larger phase angle where θ is positive in the counterclockwise direction on the conventional complex Z plane.

1.7 GENERAL RECOMMENDATIONS.

The general operation of this instrument is simple and straightforward. However, this instruction book does contain many graphs and charts, which are useful at the extremes of the various ranges and which are helpful in interpreting the meter indications. If the operation of the instrument is understood, reference to these charts is often unnecessary.

Measurement errors are most likely to result from either of two causes:

1. The standard and unknown impedances are so large that the input impedance of the detecting circuit affects the measurement (refer to paragraph 3.11).

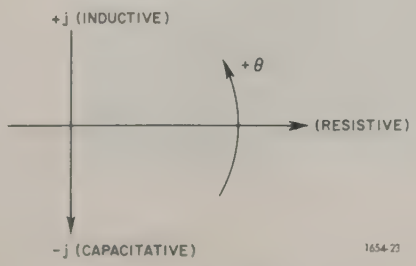


Figure 1-4. Definition of sign of θ.

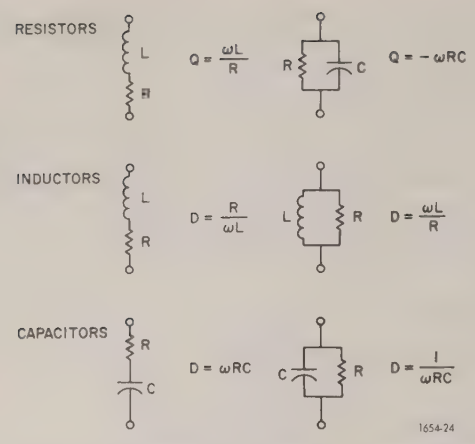


Figure 1-5. Definition of D and Q for series and parallel elements.

2. A very small $\Delta\theta$ is to be observed in the presence of a large ΔZ, or vice versa (refer to paragraph 3.13).

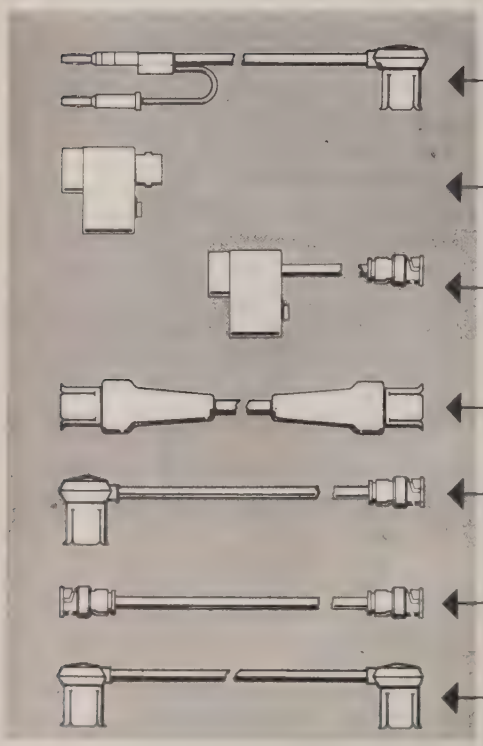
Interpreting the meter indications can cause an error if:

1. The ΔZ indication is over 3% and the MAGNITUDE LINEARIZER switch is in the OUT position.

2. The meter indications are interpreted in other than polar form when $\Delta\theta$ is large (refer to paragraphs 3.15 and 3.16).

One point should perhaps be emphasized. Occasionally, the bridge will give an indicator reading that may seem, intuitively, to be in error. Experience has shown that the bridge is correct. It is particularly important to know what is being measured and to make sure that the external components are connected properly. Most difficulties reported with similar instruments result from errors introduced by improper connection of the unknown.

TABLE 1-5
AVAILABLE INTERCONNECTION ACCESSORIES



TYPE NO.	DESCRIPTION	CATALOG NO.
874-R33	Coaxial patch cord, two plugs to GR874, 36" long	0874-9690
274-QBJ	Adaptor, shielded double plug to BNC jack	0274-9884
776-A	Patch cord, shielded double plug to BNC plug, 36" long	0776-9701
874-R22A	Coaxial patch cord GR874 to GR874, 36" long	0874-9682
776-B	Patch cord, GR874 (right-angle) to BNC plug, 36" long	0776-9702
776-C	Patch cord, BNC plug to BNC plug, 36" long	0776-9703
776-D	GR874 to GR874, both right-angle, 36" long	0776-9704

274-13XA

Installation—Section 2

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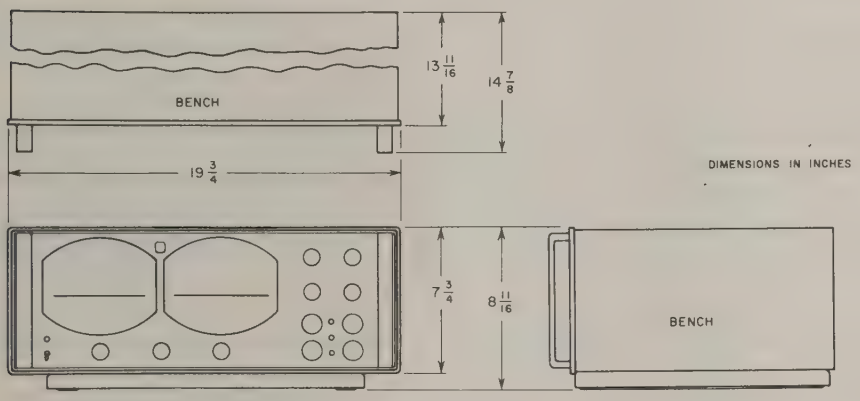

Figure 2-1. Dimensions of the bench model 1654 Impedance Comparator.

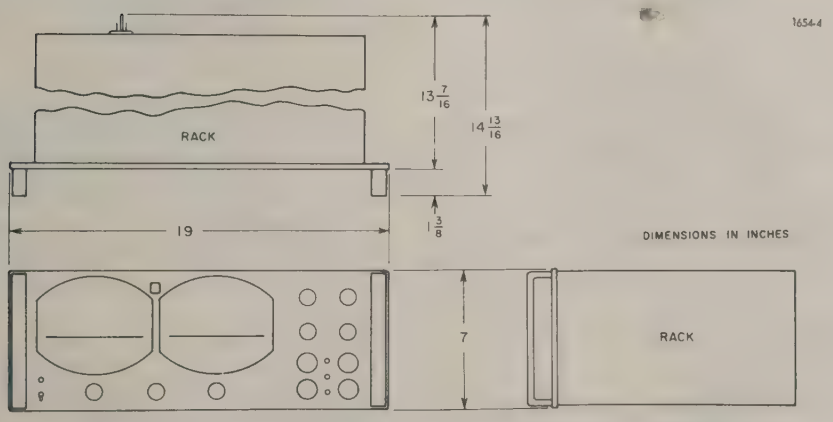

Figure 2-2. Dimensions of the relay-rack model 1654 Impedance Comparator.

2.1 GENERAL.

The 1654 Impedance Comparator is available for either bench use or for installation in an EIA standard 19-in. relay rack with universal spacing. The connectors for the standard and unknown test component are normally installed in the front panel, but these connectors can be removed and reinstalled in the rear panel.

Appropriate accessories and mounting hardware are available for conversion of the bench model for relay-rack use, or for conversion of the relay-rack model for bench use.

2.2 DIMENSIONS.

The dimensions of both the bench and relay-rack models of the 1654 are given in Figures 2-1 and 2-2.

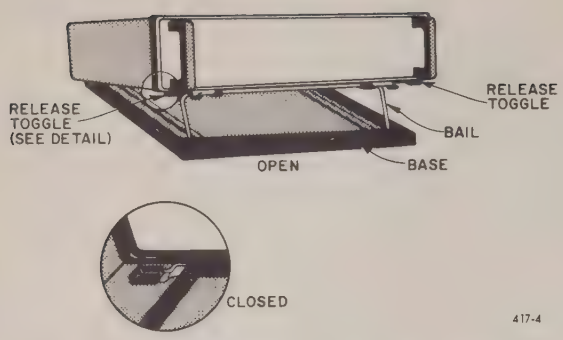

Figure 2-3. The 1654 tilted for better view of front-panel controls and indicators.

2.3 BENCH MODELS.

2.3.1 Mounting.

The bench models of the comparator are delivered completely assembled in a metal cabinet, ready for bench use. A convenient bail, located along the bottom front edge of the instrument, can be pulled down to raise the front and provide a better view of the front-panel meters and indicators (see Figure 2-3). To tilt the instrument, proceed as follows:

a. Place the right thumb on the right-hand release toggle and the left thumb on the left-hand release toggle under the front corners of the instrument.

b. Push both release toggles toward the rear as far as they will go.

c. Using the rear of the base as a pivot, lift the front of the instrument, permitting the bail to drop down on the base.

d. With one hand, hold the instrument in the tilted position; with the other, pull the bail forward as far as it will go and carefully lower the instrument. The bail is now locked place and the instrument will remain in the tilted position.

Reverse this procedure eliminate the tilt. Be sure the toggles are pushed back, toward the rear of the instrument. Then lower the front carefully onto the base. Lock the base to the bottom of the instrument by sliding the toggles forward.

2.3.2 Cabinet Removal.

To remove a bench-model instrument from its cabinet:

Remove the four panel screws (A, Figure 2-4), two on each side of the front panel. These are No. 10-32, 9/16-in. screws, with nylon washers. To loosen them, insert a Phillips-head screwdriver through the holes in the handles, as shown in the figure. Then pull the instrument forward, out of the cabinet.

2.3.3 Conversion For Rack Use.

To convert a bench model for relay-rack use, order from GR one Rackable Cabinet Assembly (refer to Table 2-1). Then proceed as follows:

a. Disconnect all cables from the rear of the instrument, remove the four panel screws (A, Figure 2-4), and pull the

TABLE 2-1
RACKABLE CABINET
(P/N 4174-3144)

Quantity	*Description*	*Part Number*
2	Cover	4174-8012
2	Side Pan	4174-8144
12	Screw, thread-forming, 8-32, 1/4	7170-1304
1	Hardware Set, consisting of:	4174-2402
4	Rivet, blind, 0.156 x 0.254	
2	Track, modified	
1	Hardware Set, consisting of:	4174-2002
4	Nut, hex, 10-32	
4	Screw, thread-forming, 8-32, 1/4	
4	Screw, dress-panel, 10-32, 9/16	
4	Washer, No. 10	
4	Washer	

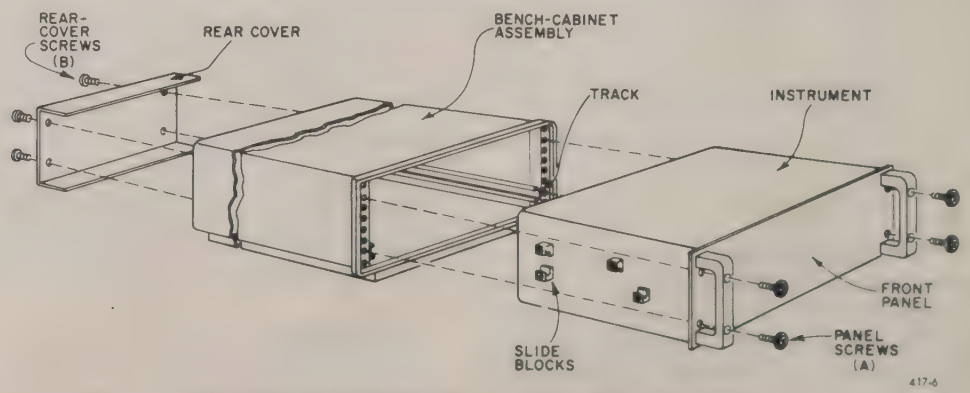

Figure 2-4. Cabinet removal and conversion for rack mounting.

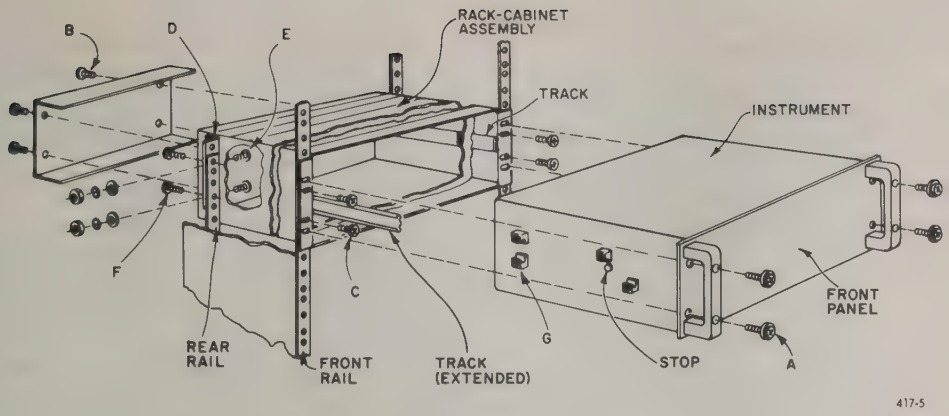

Figure 2-5. Relay-rack installation.

instrument forward, out of the cabinet (refer to paragraph 2.3.2).

b. From the rear, remove the four screws (B) holding the rear cover to the bench cabinet and remove the cover.

c. Proceed with the relay-rack installation, as given in paragraph 2.4.1.

2.4 RELAY-RACK MODELS.

2.4.1 General.

Relay-rack models of the comparator are supplied with Rackable Cabinet Assembly, P/N 4174-3144, and Hardware Set, P/N 4174-2000. The items in the Hardware Set are listed in Table 2-2.

2.4.2 Installation.

To install a rack-model instrument in an EIA standard RS-310 19-in. relay rack, with universal mounting-hole spacing, proceed as follows:

a. Remove the four panel screws (A, Figure 2-5) slide the instrument forward, out of the rack cabinet, until it stops. Raise the front edge slightly to release the stops. The instrument can then be completely removed from the rack cabinet.

b. From the rear, remove the rear-cover screws (B) holding the rear cover to the rack cabinet and remove the cover.

c. Insert the rack cabinet in the rack and secure it to the front rails of the rack with the four front-support screws (C).

d. If the rack contains a rear support, attach the brackets (D) to the rack cabinet, using the rear support screws (E), with washers and nuts. Insert the screws from inside the rack cabinet through the slotted holes in the bracket. Use the set of slots in the cabinet that properly aligns holes in the brackets with holes in the rear rail of the relay rack.

e. Secure the brackets to the rear rails, using the rear-bracket screws (F).

f. Place the rear edge of the instrument in the rack cabinet so that the rear slide blocks (G) engage the track. Slide the instrument into the cabinet, making sure that the front slide blocks also engage the tracks. Lock the instrument in the cabinet with the four panel screws (A) with nylon washers. (Tighten these screws by inserting a Phillips-head screwdriver through the holes in the handles).

g. Replace the rear cover and lock it in place using the rear-cover screws (B).

By removing the four panel screws (A), one can slide the instrument forward, out of the rack cabinet on the extend-

TABLE 2-2
HARDWARE SET SUPPLIED WITH RACK MODEL (P/N 4174-2000)

Fig. 2.5 Ref.	*Quantity*	*Description*
D	2	Brackets, L-shaped
E	8	Screws, binder-head, 10-32
	8	*Washers, flat, No. 10
	8	*Washers, locking, No. 10
	8	*Nuts, hex, 10-32
F	4	Screws, pan-head, thread-cutting 10-32, 1/2 in. for rear bracket where required.

*For use with 10-32 screws as required.

able tracks (see Figure 2-5). The tracks will still support the instrument for easy access to its interior.

2.4.3 Conversion For Bench Mounting.

To convert a relay-rack model for bench use, order a Bench Cabinet Assembly complete. Then, remove the rear-cover screws (B, Figure 2-5) and remove the rear cover. Follow the reverse procedure described in paragraph 2.3.2.

2.5 POWER-LINE CONNECTION.

With the comparator placed in position on a bench or in a relay rack, set the recessed slide switch (7, Figure 1-3) on the rear panel to the range corresponding to the power-line voltage to be used Connect the instrument to the power source using the 3-terminal power cord supplied (P/N 4200-9622, Table 1-3). Turn on the POWER/OFF switch on the front panel

Two Slo-Blo fuses are installed in the fuse holders on the rear panel A 1/10-A fuse is used for 230-V operation; a 15/100-A fuse is used for 115-V operation (9, Figure 1-3).

2.6 TEST CONNECTORS AT REAR.

2.6.1 General.

The STANDARD and UNKNOWN connectors, as well as the three jacks (8 through 12, Figure 1-2) are normally mounted on the front panel For some applications, it may be desirable to connect the test components at the rear of the instrument; this can be done by removing these connectors (as a single unit) and remounting them in the openings provided under the cover plate (1, Figure 1-3) on the rear panel The following paragraphs described this procedure.

2.6.2 Procedure.

First remove the cabinet (refer to paragraph 2.3.2) and turn the instrument upside down.

NOTE

It is assumed that the connectors are to be removed from the front panel and installed at the rear. If the connectors are to be moved from the rear to the front panel, the procedure is essentially the same.

The procedure is as follows:

a. On the rear panel: remove the two sets of Phillips-head screws and their associated nylon washers (A, Figure 2-6), nylon washers (B), flat washers (C), lockwashers (D), and nuts (E).

b. Remove the cover plate and retain all parts.

c. On the front panel (see Figure 2-7): Remove and retain the upper and lower (not the center or ground jack) jacks with nylon washers (F), flat washers (G), lockwashers (H), and nuts (I).

NOTE

The bottom (GUARD) jack is not secured with a nut; it is threaded into a tapped hole in a spacer block that is attached to the connector unit.

d. Slide the connector unit, containing the four GR874 connectors, back and out.

e. Remove the ground (center) jack and install it in the center hole in the rear panel.

f. Refer to Figure 2-8. Remove the plastic cable-holder clip with a Phillips-head screwdriver and retain all parts.

g. Swing the connector around (180°, horizontally) and slide it into position in the rear panel.

NOTE

Be sure to insert the correct set of GR874 connectors into the appropriate openings in the rear panel. Make note of the colored leads attached to each set of connectors; blue for the UNKNOWN set and orange for the STANDARD set.

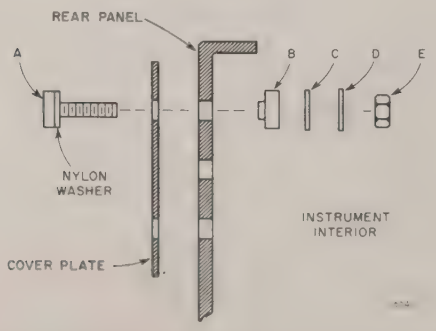

Figure 2-6. Removal of cover plate from rear panel.

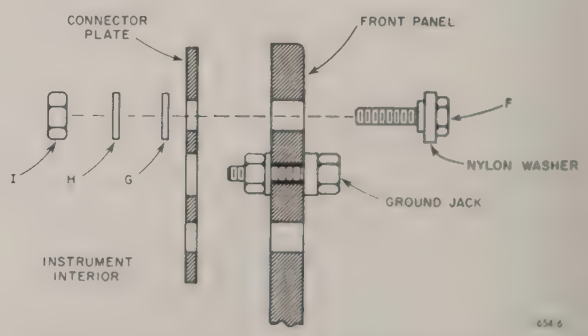

Figure 2-7. Removal of connector plate from front panel.

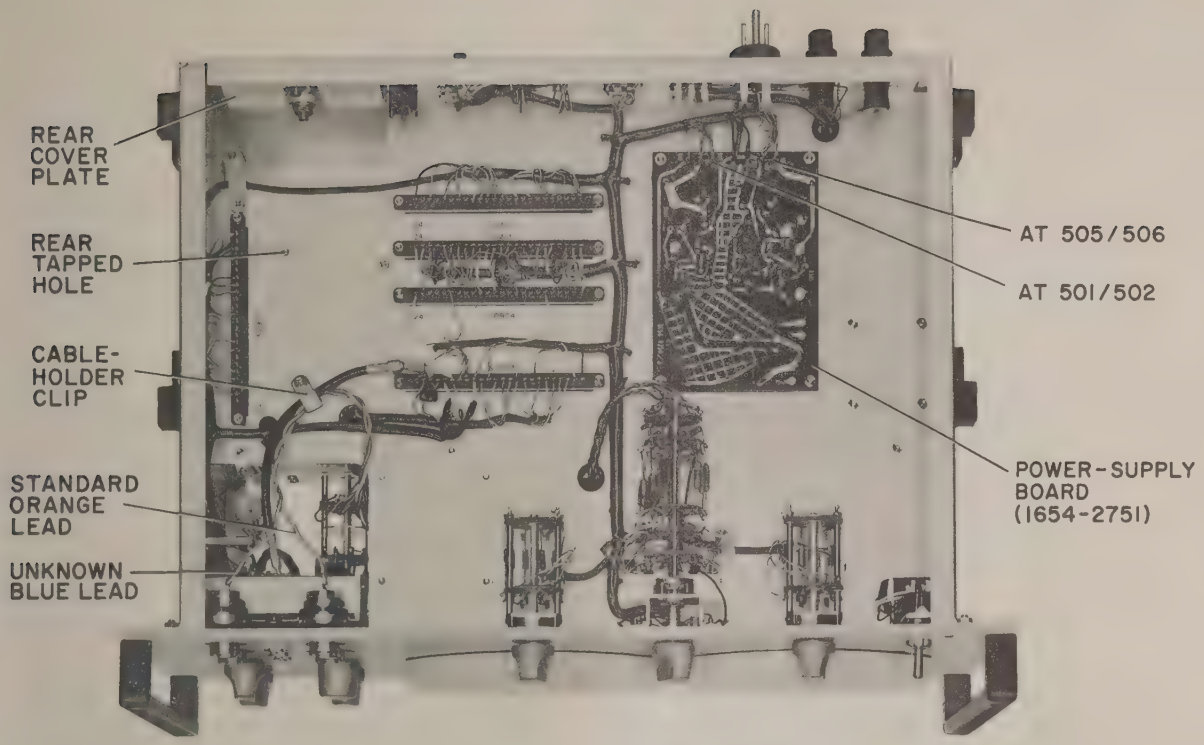

Figure 2-8. Bottom interior of 1654 with connectors installed in the front panel.

h. Refer to Figure 2-7. Install the two jacks (parts F through I) that were previously removed from the front panel.

CAUTION

Prevent accidental grounding of the GR874 connectors; be sure that the metal connectors and their mounting plates do not touch the rear panel when the upper and lower jacks are secured.

i. Install the plastic cable-holder clip, previously removed in step f, in the rear tapped hole (see Figure 2-8).

j. Mount the cover plate (see Figure 2-6) on the front panel, using the previously removed hardware (parts A through E).

The instrument is now ready for installation in a relay rack, or for bench use, once it is reinstalled in its cabinet.

2.7 LINE-VOLTAGE REGULATION.

The accuracy of measurements accomplished with precision electronic test equipment operated from ac line sources can often be seriously degraded by fluctuations in primary input power. Line-voltage variations as great as ±5% are commonly encountered, even in laboratory environments.

Although most modern electronic instruments incorporate some degree of line-voltage regulation, serious consideration to possible power-source problems should be given for every instrumentation set-up. The use of line-voltage regulators between power lines and the test equipment is recommended to prevent undesirable effects of low line voltage, transients, and other power phenomena.

The General Radio 1591 Variac® Automatic Voltage Regulator is a compact and inexpensive instrument that is capable of regulating ac power within ±0.2% accuracy for up to a rack full of solid-state instrumentation. The 1591 has a basic capacity of 1 kVA, with no distortion of the input waveform. This rugged electro-mechanical regulator is available for bench or rack use, both of which permit direct plug-in of measurement-instrument power cords.

Further details can be found in the GR catalog, or in the GR *Experimenter* for October, 1967.

Operation–Section 3

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3.1 GENERAL.

The operating procedure in paragraphs 3.1 thru 3.8 is the general procedure for comparing components that are well within the ranges of the 1654 Impedance Comparator. For measurement of impedances at the extremes of the range and for error corrections, refer to paragraphs 3.9 thru 3.16. For special measurements and applications, refer to Section 4.

Install the bridge as described in Section 2 and turn the POWER/OFF switch on. When the instrument is first turned on, the meters will momentarily indicate off-scale and the OFF SCALE indicator lamp will light. After a few seconds, the meter pointers should come to rest near zero (midscale) if the INPUT switch is set to ZERO.

Although measurements can be made as soon as the bridge is operative, it is desirable to wait about 30 seconds to stabilize the oscillator and meter circuits. After this period of time, the meter drift should be very small and rechecking of the zero is not necessary except for the most precise measurements using the most sensitive deviation range.

3.2 CONNECTION OF STANDARD AND UNKNOWN.

Because so many different types of components can be measured with this comparator, it is impossible to design a suitable terminal arrangement to accomodate all measurements. The terminals on the instrument itself were designed to have small capacitance. For measurements unaffected by

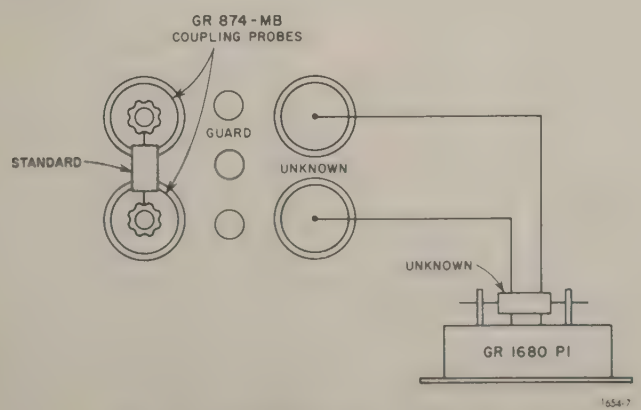

Figure 3-1. Test setup using the 1680-P1 Test Fixture and 874-MB Coupling Probes.

a moderate amount of input capacitance, connections can be simplified by means of the GR 1680-P1 Test Fixture for the unknown and two GR 874-MB Coupling Probes or an adaptor plate (refer to Table 1-4) for the standard, as shown in Figure 3-1.

When low-impedance measurements are made, it is necessary to make sure that the connections have negligible resistance. In some cases, it is desirable not to use the 1680-P1 Test Fixture due to lead and contact impedances. Direct connection can be made using GR 874-MB Coupling Probes.

For high-impedance measurements, it is desirable not to add any capacitance to ground from the common terminal (refer to paragraph 3.11). If the unknown is encased and the case is connected to one terminal, it is desirable to connect this terminal to a transformer terminal. Note also that capacitance between leads connecting external components effectively changes the value of these components.

Special jigs will be required for some applications. Remember that such a jig will be in the bridge circuit so that series impedance and stray capacitance should be carefully considered.

3.3 FREQUENCY SELECTION.

The comparator provides internal frequencies of 100 Hz, 1 kHz, 10 kHz, and 100 kHz. Set the FREQUENCY switch to the desired position.

For most measurements, it is desirable to consider the test frequency, in order that the information presented will be useful, and so that the high-impedance limitation is not exceeded (refer to paragraph 3.11).

3.4 ZEROING.

To zero both meters, set the INPUT switch to ZERO position and adjust the zero adjustments to set the meters to zero, with both deviation ranges set at the most sensitive range. Once the instrument is warmed up, it should not be necessary to check meter zero, except for the most precise measurements. Meter drift should be less than 1% of full scale for at least a day on the most sensitive range and negligible on the less sensitive ranges.

As the frequency is changed, the meter zeros should move less than 1% of full scale, so that rezeroing is usually not necessary.

3.5 CALIBRATION.

To calibrate the instrument, set the MAGNITUDE DIFFERENCE control to 1 and the INPUT switch to CAL 1%. Adjust the CALIBRATE control to obtain the 1% (full-scale) indication on the MAGNITUDE DIFFERENCE meter. Ignore the $\Delta\theta$ reading.

For most accurate measurements, the calibration should be rechecked if the test frequency is changed. For frequencies of 1 kHz and 10 kHz, the calibration level should be constant to about 1% as the frequency is changed, so that resetting is usually not necessary. At 100 Hz, the calibration level is about 3% lower than 1 kHz. At 100 kHz, the calibration level is about 6% higher than at 1 kHz.

When low impedances (below 20 Ω) are being measured, it is desirable to set the calibration level with the external components connected (refer also to paragraph 3.10).

3.6 TEST-VOLTAGE AND RANGE SELECTIONS.

Test voltage and measurement ranges are related and their panel switches are interlocked to reflect this relationship. Four measurement ranges can be used with each test voltage. The largest test voltage (3 V) gives the greatest sensitivity. The lower test voltages (1 V and 0.3 V) limit maximum sensitivity and extend large-difference capability to 10% and 30% full scale, respectively.

The desired deviation ranges are set by the MAGNITUDE DIFFERENCE and PHASE ANGLE DIFFERENCE switches. These switches indicate the full-scale value of the meters.

Note that there is a possibility of error in measurement on the most sensitive range if the other meter is indicating on its least sensitive range (refer to paragraph 3.13).

3.7 GUARD CIRCUIT.

The GUARDED and UNGUARDED positions of the INPUT switch are the same except for the potential of the outer conductors of the upper two 874 coaxial connectors, which are common. When the control is switched to UNGUARDED, the outer conductors are grounded. In the GUARDED switch position, the outer conductor is driven at nearly the same potential as the inner conductor (detector input) and therefore acts as a guard circuit. This results in a substantially lower input capacitance.

With the INPUT switch in the GUARDED position, oscillation and actuation of the OFF SCALE indicator is possible when measuring some inductors. The UNGUARDED position should be used if such oscillations occur.

3.8 MEASUREMENT.

Turn the comparator on and allow it to warm up. Zero the meters and calibrate the instrument, if necessary.

Connect accessory equipment, such as DVM, recorder, or 1782 Analog Limit Comparator to the rear panel and set the appropriate controls.

Set the instrument controls. Refer to Tables 1-1 and 1-2, and the above paragraphs for a complete description of the use and function of all controls on the 1654.

Connect the standard and unknown components, using appropriate test fixtures, if necessary (refer to paragraph 3.2). Set the MEASUREMENT switch to either the RESISTANCE/INDUCTANCE or the CAPACITANCE position, depending on the type of component to be measured.

With the instrument zeroed and calibrated, and the components properly connected, the meters will indicate the desired readings when the INPUT switch is set to either the GUARDED or UNGUARDED position.

3.9 RANGES AND ERRORS.

3.9.1 General.

The remainder of this section deals with the identification and correction for possible errors, and extension of normal measurement ranges.

The FREQUENCY switch provides four test frequencies of 100 Hz, 1 kHz, 10 kHz, and 100 kHz. It is not possible to use an external oscillator for other frequencies since the phase-shift networks also depend upon the frequency. The fixed capacitors of the oscillator and phase-shift network could be changed to produce other fixed frequencies, but this is a rather complicated procedure.

The deviation ranges provided are 0.1, 0.3, 1, 3, 10 and 30% full-scale for ΔZ, and 0.001, 0.003, 0.01, 0.03, 0.1, and 0.3 radian full-scale for $\Delta\theta$.

The impedance range is quite wide. The range limitations are simple at the low end (refer to paragraph 3.10) but become more complex at the high end (refer to paragraph 3.11).

The choice of several test frequencies permits wide ranges of C and L. All these ranges are not possible at one particular frequency.

Paragraph 3.13 lists the possible errors that may occur in measurement. These errors are negligible compared with the overall 3% accuracy for most measurements.

TABLE 3-1
R, L, AND C LIMITS

Frequency	*Test Voltage*	*R (Ω)*	*L*	*C (μF)*
100 Hz	0.3 V	2	5 mH	1000
	1 V	20	50 mH	100
	3 V	200	500 mH	10
1 kHz	0.3 V	2	500 μH	100
	1 V	20	5 mH	10
	3 V	200	50 mH	1
10 kHz	0.3 V	2	50 μH	10
	1 V	20	500 μH	1
	3 V	200	5 mH	0.1
100 kHz	0.3 V	10	20 μH	0.1
	1 V	100	200 μH	0.01
	3 V	1000	2 mH	0.001

3.10 MEASUREMENT OF LOW IMPEDANCES.

3.10.1 Normal Limits.

The low end of the impedance range is limited by the power available from the transformer and the source impedance of the primary circuit. The ranges for R, L, and C values of external components are listed in Table 3-1.

It will be impossible to obtain sufficient bridge voltage to calibrate the instrument if the unknown components are of substantially lower impedance than the values in Table 3-1 (i.e., about 1/2 the values given).

As these values are approached, the bridge voltage will be slightly reduced when the components are connected, so that the calibration should be made with the components in place. At 100 kHz, the bridge voltage may actually increase with a large capacitive load due to resonance with the transformer inductance. Also, as these values are approached, there may be an increase in the error at opposite deviation extremes, due to distortion resulting from oscillator loading (refer to paragraph 3.13).

It is necessary, in order to avoid errors, to make low-impedance connections to the unknown. These connections should be made directly to the panel terminal, via GR874-MB connectors, if small deviations are to be detected. The smallest resistance difference that the comparator can detect is 0.03% x 2 Ω = 600 μΩ. The difference in output impedance between the two secondary windings is substantially lower than this so that it causes negligible error.

3.10.2 Extending The Low-Impedance Range.

A useful method of extending the range to lower impedances is to put equal impedances (R) in series with both the standard (R_s) and unknown (R_x) so that the total impedance is above the limit. With this method, both the ΔZ and $\Delta\theta$ readings must be corrected.

$$\underset{\text{Reading}}{\frac{R_x - R_s}{R + \frac{R_s}{2}}} \times \underset{\text{Correction}}{\frac{R + \frac{R_s}{2}}{\frac{R_s}{2}}} = \underset{\text{Desired}}{\frac{R_x - R_s}{\frac{R_s}{2}}}$$

As an example, the correction for measuring resistance difference is given above. The resistors (R) need not be equal since it is possible to determine the difference and correct for it.

3.11 MEASUREMENT OF HIGH IMPEDANCES.

With instruments of this type, where the bridge output is measured rather than brought to a balance, the high end of the impedance range is limited by the input impedance of the detecting or measuring circuit. In this instrument, the input circuit was designed with this in mind.

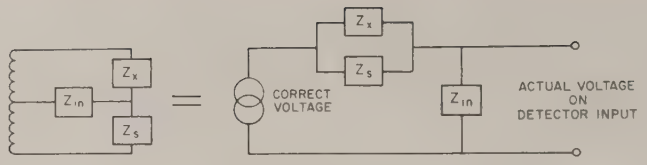

Figure 3-2. Equivalent circuit of bridge circuit loaded by the input impedance of the detector.

With the INPUT switch in the GUARDED position, the input impedance is about 1 pF in parallel with over 1000 MΩ. In the grounded position, capacitance is increased to approximately 43 pF.

The effect of this finite impedance is to attenuate the signal and shift its phase. This effect can be easily seen by the equivalent circuit of Figure 3.2. For some applications, the equivalent circuit of Figure 3-3 is useful.

The effect of the attenuation is easy to calculate. For example, if the input resistance is 1000 MΩ (at such a frequency that the capacitance is negligible), there will be an error of approximately 1% when 20-MΩ resistors are measured.

The effect of the phase shift is more difficult to correct for, since it is a function of the frequency, the external impedance, and both meter readings. An unbalance voltage that was real (magnitude only), for example, would be shifted in phase, resulting in a $\Delta\theta$ meter reading.

The charts of Figures 3-4 through 3-7 are given to show quickly the limitations for measuring various components at the various frequencies.

With an input admittance, Y_{in}, the actual bridge voltage is proportional to:

$$-2\frac{Y_x - Y_s}{Y_x + Y_s + Y_{in}}$$

For the correct reading, a correction factor is necessary:

$$-2\frac{Y_x - Y_s}{Y_x + Y_s + Y_{in}} \times \frac{Y_x + Y_s + Y_{in}}{Y_x + Y_s}$$

$$= -\frac{\frac{Y_x - Y_s}{2}}{\frac{Y_x + Y_s}{2}} = \frac{Z_x - Z_s}{Z_x + Z_s}$$

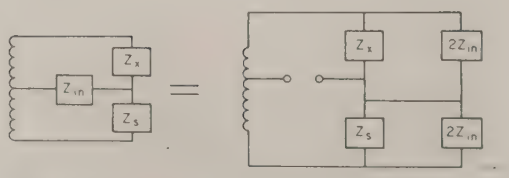

Figure 3-3. Alternate equivalent circuit of the loaded bridge circuit.

If we let this correction factor be:

$$\frac{Y_x + Y_s + Y_{in}}{Y_x + Y_s} = 1 + \frac{Y_{in}}{Y_x + Y_s} = 1 + A + jB$$

where $A = \text{Re}\dfrac{Y_{in}}{Y_s + Y_x}$

$$B = \text{Im}\frac{Y_{in}}{Y_s + Y_x}$$

or since: $Y_s \approx Y_x$

$$A \approx \text{Re}\frac{Y_{in}}{2Y_s}$$

$$B \approx \text{Im}\frac{Y_{in}}{2Y_s}$$

we can write:

$$\Delta Z_T = \Delta Z_A\,(1 + A) - B\Delta\theta_A$$
$$\Delta\theta_T = \Delta\theta_A\,(1 + A) + B\Delta Z_A$$

where the subscript T refers to the true value and A to the actual value read on the meters; also $\Delta\theta$ and ΔZ are expressed as decimals (i.e., 1% = 0.01).

Note that A and B may be positive or negative (refer to equations in Figures 3-4, 3-5, and 3-6).

The A term is the magnitude correction and causes a percent error, so that it is negligible if less than 0.02 (2%). The B term is the effect of phase shift and results in an additive error, so that its effect is worse on the most sensitive ranges.

The values of A and B are plotted in Figures 3-4, 3-5, and 3-6 for different types of components (R, C, and L) at different frequencies with a nominal input impedance of 1 pF in parallel with 1000 MΩ.

The error terms involving B above, also include the reading of the other meter. This means that to find the ΔZ error, one has to know $\Delta\theta_A$ as well as B. It is easy to calculate $B\Delta Z$, or $B\Delta\theta_A$, or the chart of Figure 3-7 can be used to avoid mistakes.

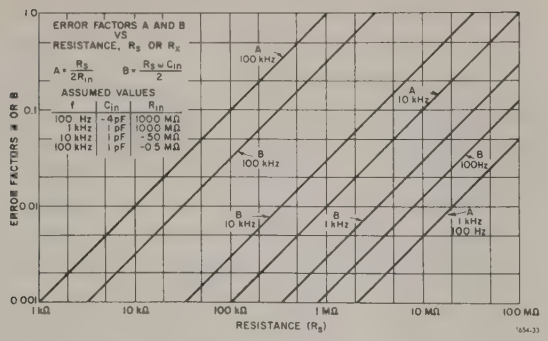

Figure 3-4. Factors A and B vs resistance.

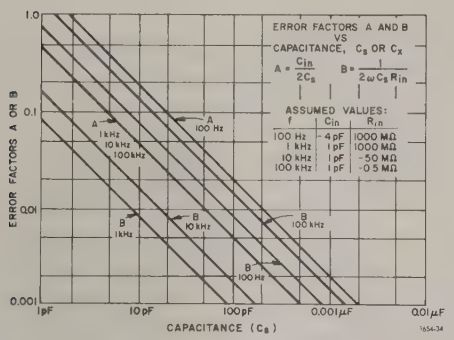

Figure 3-5. Factors A and B vs capacitance.

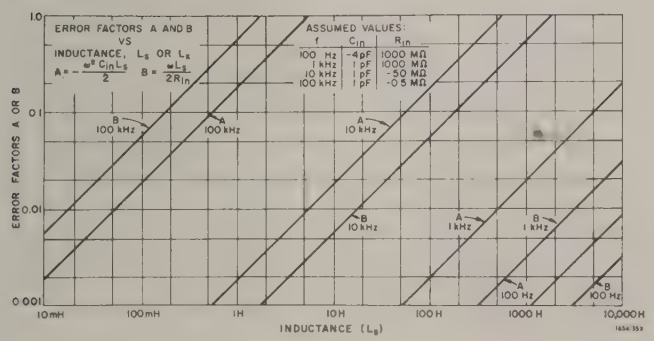

Figure 3-6. Factors A and B vs inductance.

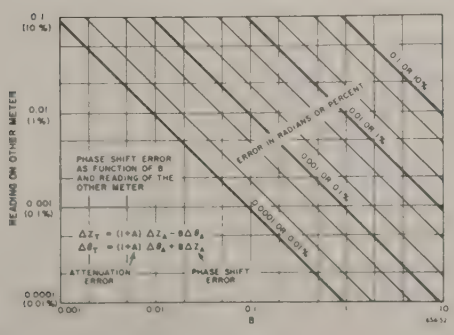

Figure 3-7. Phase-angle error as a function of B and ΔZ range or magnitude error as a function of B and $\Delta\theta$.

These charts are designed primarily to show the range possible rather than to attempt to make corrections for measurements outside the range. Crude corrections are possible, but precision is difficult due to added input impedance resulting from the actual physical connection of the components, which is hard to determine.

Hum pickup can also cause appreciable difficulty when high-impedance (at 60 Hz) components are measured. A slight amount of hum pickup should cause no error in the readings except for a beating vibration when the 100-Hz test frequency is used. Large hum pickups, however, may cause the off-scale indicator to be actuated, which shorts the signal channels to ground.

Usually this pickup difficulty can be overcome by proper shielding of the components under test. Grounding the instrument is usually necessary, as well as grounding any nearby equipment.

3.12 LARGE ΔZ DEVIATIONS.

With the MAGNITUDE LINEARIZER switched to the OUT position, the instrument measures the impedance difference as a percent of the average between standard and unknown, rather than a percent of the standard. When measuring large ΔZ deviations, 10% for example, the approximation in going from $\frac{|Z_x| - |Z_s|}{\frac{|Z_x| + |Z_s|}{2}}$ to $\frac{|Z_x| - |Z_s|}{|Z_s|}$ results in an error of 0.5%. At a 5% deviation, this error is only 0.13%, which is less than the general accuracy statement of 3%, so that the correction can generally be omitted.

With the MAGNITUDE LINEARIZER switched IN, the usual nonlinearity of the bridge output is compensated to indicate the magnitude difference expressed as a percent of the standard on both the 10% and 30% full-scale ranges.

3.13 POSSIBLE ERRORS.

Within the deviation ranges of the instrument (30% and 0.3 radian), the basic bridge equations (refer to paragraph 5.3.1) give the desired magnitude difference and phase-angle difference with negligible error, except for the 10% and 30% ranges where compensation is required to give the desired readout. This information, presented in polar form, can be interpreted in terms of ΔR, ΔL, or ΔC, and ΔD and ΔQ for many measurements (refer to paragraphs 3.15 and 3.16).

This bridge output voltage, of course, can be in error if the impedance range is exceeded, so that it is important to make sure the standard and unknown components are within the range (refer to paragraphs 3.10 and 3.11).

The instrument may produce small errors above the specified 3% when the meters are used at opposite range extremes; that is, when one meter is near full scale on its least sensitive range and the other reading on its most sensitive range. The error occurs on the more sensitive meter.

These errors result from several causes. Under the above conditions, the synchronous-switching operation of the phase-sensitive detector of the sensitive meter causes a slight error because the signal voltage, that is largely in quadrature with the reference square-wave voltage, becomes large. The desired result is the difference of two large integrals, which is very small. This error is a function of both frequency and deviation. In the worst case, when the coarse meter is indicating 30% or 0.3 radian, the reading on the sensitive meter is in error by the amount shown in Table 3-2.

TABLE 3-2
SENSITIVE-METER ERRORS

Frequency	ΔZ	$\Delta\theta$
100 Hz	0.0001%	0.000002
1 kHz	0.001%	0.00002
10 kHz	0.01%	0.0002
100 kHz	0.1%	0.001

Under the same conditions of opposite range extremes, a small error in the phase of the quadrature voltage causes some of the large quadrature voltage to appear in phase with the reference. This phase-shift error in the reference voltage can be caused by a changed value of the components in the oscillator or phase-shift network. The ΔZ reference is less susceptible to this error, since the phase shift is small. The $\Delta\theta$ reference shift is minimized because of the like resistors and capacitors in components in the oscillator or phase-shift network, which cause the effects of temperature to cancel to some degree.

Changes in harmonic distortion in the signal voltage will cause an effective phase-shift change since the harmonics of the reference are not at the correct phase.

Both these errors are proportional to the reading of the other meter and should be only a few percent of full scale when the other meter is reading 30% or 0.3 radian.

Another error is possible when the instrument is operating near the extremes of its temperature range (the normal temperature range is 10 - 40° C). Under these conditions, the cross-term factors in Table 3-3 can be applied to calculate the correction required for higher accuracy.

TABLE 3-3
CROSS-TERM FACTORS FOR TEMPERATURE CORRECTION
A Factor

Frequency	$-\Delta T$ *(ppm)*	$+\Delta T$ *(ppm)*
100 Hz	+ 2	– 2
1 kHz	+ 1	– 1
10 kHz	+ 2	– 2
100 kHz	– 2	– 2

Cross-term correction = A x other reading in %/°C x ΔT (where T nominal = 25° C). As an example, at 40° C and a frequency of 10 kHz, if the ΔZ reading = 16% and the $\Delta\theta$ reading = –0.0012 radian, the correction for the $\Delta\theta$ reading is:

θ (corrected) = $\Delta\theta$ + cross-term correction
= $-0.0012 + 2 \times 10^{-6} \times 16 \times 15$)
= –0.0012 + 0.00048
= –0.00072 radian

The largest source of error is the 1% meter itself. This can produce an error of 2% of full scale since the meter is zero centered. Thus the over-all accuracy is about 3% of full scale for most measurements. With careful zeroing, measurements about zero can easily have greater precision, so that the actual ultimate precision is better than 0.003% (0.00003 radian) for the 0.1% full-scale deviation range.

3.14 UNBALANCED LOADING ON TRANSFORMER.

Impedance placed across one side of the transformer to ground has little effect due to the tight coupling of the 1:1 ratio toriodal bridge transformer. This feature has important advantages for many measurements since stray impedances may be placed across one transformer winding. Figure 3-8 shows an equivalent circuit, with shunt impedances Z_1 and Z_2 across the two balanced windings. Here I_p, r_p, l_s and r_s do not cause an unbalance because both E_1 and E_2 are reduced by a voltage drop in the primary.

If the leakage inductance and resistance are assumed equal for the two bridge windings (a very good approximation), it can be shown that the only important error is a fixed, additive error of:

$$\Delta Y\ (r + j\omega\ell)$$

where $\Delta Y = Y_1 - Y_2 = \frac{1}{Z_1} - \frac{1}{Z_2}$

which is most important on the most sensitive ranges. If only one side is loaded with an impedance, Z, the error becomes:

$$\frac{r + j\omega\ell}{Z} = Y\ (r + j\omega\ell)$$

where the error is positive if placed across the unknown half of the bridge winding. The value of r is about 0.9 Ω and the value of ℓ is about 2.8 μH.

Table 3-4 gives equations for calculating ΔZ and $\Delta\theta$ errors for various loads at the various frequencies. The ΔZ errors should be multiplied by 100 to give the percent error. The sign of the error is correct if the unknown transformer terminal is loaded.

Example: Shunting the unknown side of the transformer with 100 Ω at 10 kHz will cause a ΔZ error of less than 0.9/100 x 100% = 0.9% and a $\Delta\theta$ error of less than $17.5/100 \times 10^{-2} = 0.0017$ radian.

3.15 MEASUREMENTS OF R, L, OR C DIFFERENCES.

The ΔZ meter can be interpreted as a ΔR, ΔL, or ΔC difference with negligible error if the standard elements are relatively pure. Obviously, if the components are pure, the impedance magnitude is equal to the value of R, L, or C, as the case may be. If the components are not pure, but ΔD or ΔQ equals zero, no error will result from considering the ΔZ indication as an R, L, or C difference, since the complex

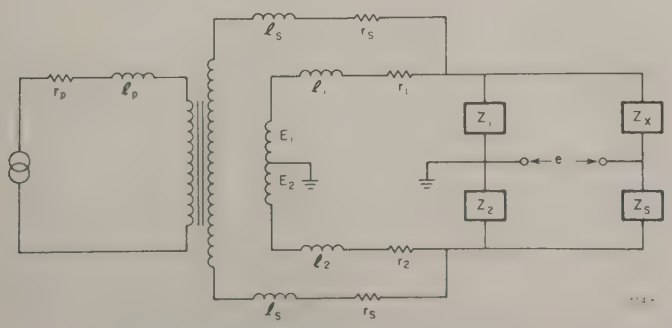

Figure 3-8. Equivalent circuit of a transformer.

TABLE 3-4

EQUATIONS FOR CALCULATING ΔZ AND Δθ ERRORS

	ΔError (Multiply by 100%)			*Δθ Error (Radians)*		
Type of Load	R (Ω)	L (H)	C (μF)	R (Ω)	L (H)	C (μF)
Error Equation	$\frac{r}{R}$	$\frac{\ell}{L}$	$\omega^2 \ell C$	$\frac{\omega \ell}{R}$	$-\frac{r}{\omega L}$	$\omega r C$
Frequency	$\frac{0.9}{R}$	$\frac{2.8}{L} \times 10^{-6}$	$-1.1\ C \times 10^{-6}$	$\frac{1.75}{R} \times 10^{-3}$	$\frac{-1.43}{L} \times 10^{-3}$	$6.3\ C \times 10^{-4}$
1 kHz	$\frac{0.9}{R}$	$\frac{2.8}{L} \times 10^{-6}$	$-1.1\ C \times 10^{-6}$	$\frac{1.75}{R} \times 10^{-2}$	$\frac{-1.43}{L} \times 10^{-4}$	$6.3\ C \times 10^{-3}$
10 kHz	$\frac{0.9}{R}$	$\frac{2.8}{L} \times 10^{-6}$	$-1.1\ C \times 10^{-2}$	$\frac{1.75}{R} \times 10^{-1}$	$\frac{-1.43}{L} \times 10^{-5}$	$6.3\ C \times 10^{-2}$
100 kHz	$\frac{0.9}{R}$	$\frac{2.8}{L} \times 10^{-6}$	$-1.1\ C$	$\frac{1.75}{R}$	$\frac{-1.43}{L} \times 10^{-6}$	$0.63\ C$

impedance vectors of the two components form similar triangles so that:

$$\frac{\Delta|Z|}{|Z|} = \frac{\Delta R}{R} = \frac{\Delta X}{X}$$

The above relationship is useful, since a variable element can often be used to null the Δθ meter and thus determine accurate ΔR, ΔL, or ΔC readings where large corrections would otherwise be necessary.

The ΔZ readings can be corrected to give the R, L, or C differences, if the D or Q of the standard is known and the Δθ meter indication is used. Note that the corrections below consist of a multiplying factor (percent error) and an additive correction (fixed error), and that the factor is important only as D_s (Q_s) is larger than 0.2, where the error is 2% (if ΔD or ΔQ = 0.1).

The following equations are given for determining the various equivalent series and parallel components of complex impedances. In these expressions, the sign of Δθ is as indicated on the Δθ meter and the sign of D_s or Q_s is positive except for capacitive resistors (refer to paragraph 1.6).

Note: If the standard component is pure ($D_s = 0$ or $Q_s = 0$), the following expressions are greatly simplified.

1. Equivalent series resistance,

$$\frac{\Delta R}{R} = \frac{\Delta|Z|}{|Z|}(1 - Q_s\Delta\theta) - Q_s\Delta\theta - \frac{(\Delta\theta)^2}{2}$$

Note: Q_s is positive if the resistor is inductive, negative if the resistor is capacitive.

2. Equivalent series inductance or inductive reactance.

$$\frac{\Delta X_L}{X_L} = \frac{\Delta L}{L} = \frac{\Delta|Z|}{|Z|}(1 + D_s\Delta\theta) + D_s\Delta\theta - \frac{(\Delta\theta)^2}{2}$$

3. Equivalent series capacitance or capacitive reactance,

$$\frac{\Delta X_c}{X_c} = \frac{\Delta C}{C} = \frac{-\Delta Y}{Y}(1 + D_s\Delta\theta) + D_s\Delta\theta - \frac{(\Delta\theta)^2}{2}$$

4. Equivalent parallel conductance or resistance,

$$\frac{\Delta G}{G} = \frac{-\Delta R}{R} = \frac{-\Delta|Z|}{|Z|}(1 - Q_s\Delta\theta) - Q_s\Delta\theta - \frac{(\Delta\theta)^2}{2}$$

5. Equivalent parallel capacitance or capacitive susceptance,

$$\frac{\Delta B_c}{B_c} = \frac{\Delta C}{C} = \frac{\Delta Y}{|Y|}(1 + D_s\Delta\theta) + D_s\Delta\theta - \frac{(\Delta\theta)^2}{2}$$

Δθ is negative if the standard is the purer component.

6. Equivalent parallel inductance or inductive susceptance,

$$\frac{\Delta B_L}{B_L} = \frac{-\Delta L}{L} = \frac{-\Delta|Z|}{|Z|}(1 + D_s\Delta\theta) + D_s\Delta\theta - \frac{(\Delta\theta)^2}{2}$$

Note: Δθ is negative if the standard is the purer component.

TABLE 3-5
INTERPRETATION OF METER SIGNS

When Measuring	ΔZ Meter: Meter Reads: (With MAG. LIN. IN)	ΔZ Meter: Meter Reads: (With MAG. LIN. OUT)	ΔZ Meter: + indication means	Δθ Meter: Meter Reads	Δθ Meter: + indication means:
ΔZ	$\frac{\lvert Z_x\rvert - \lvert Z_s\rvert}{\lvert Z_s\rvert}$	$\frac{\lvert Z_x\rvert - \lvert Z_s\rvert}{\frac{\lvert Z_x\rvert + \lvert Z_s\rvert}{2}}$	Unknown has larger impedance	$\theta_x - \theta_s$	Unknown has larger θ (measured ccw on Z plane)
ΔY	$\frac{\lvert Y_x\rvert - \lvert Y_s\rvert}{\lvert Y_s\rvert}$	$\frac{\lvert Y_x\rvert - \lvert Y_s\rvert}{\frac{\lvert Y_s\rvert + \lvert Y_x\rvert}{2}}$	Unknown has larger admittance	$(\phi_x - \phi_s)$	Unknown has larger ϕ or smaller θ
ΔR	$\frac{R_x - R_s^*}{R_s}$	$\frac{R_x - R_s^*}{\frac{R_x + R_s}{2}}$	Unknown the larger resistor	$Q_x - Q_s$••	Unknown more inductive (less capacitive)
ΔL	$\frac{L_x - L_s^*}{L_s}$	$\frac{L_x - L_s^*}{\frac{L_x + L_s}{2}}$	Unknown the larger inductor	$-(D_x - D_s)$••	Unknown has less loss (higher Q)
ΔC	$\frac{C_x - C_s^*}{C_s}$	$\frac{C_x - C_s^*}{\frac{C_s + C_x}{2}}$	Unknown the larger capacitor (smaller reactance)	$-(D_x - D_s)$••	Unknown has less loss (smaller D)

•Good only for pure elements (refer to paragraph 3.15).

••Good only if both D_s and D_x (or Q_s and Q_x) are less than 0.1 (refer to paragraph 3.16).

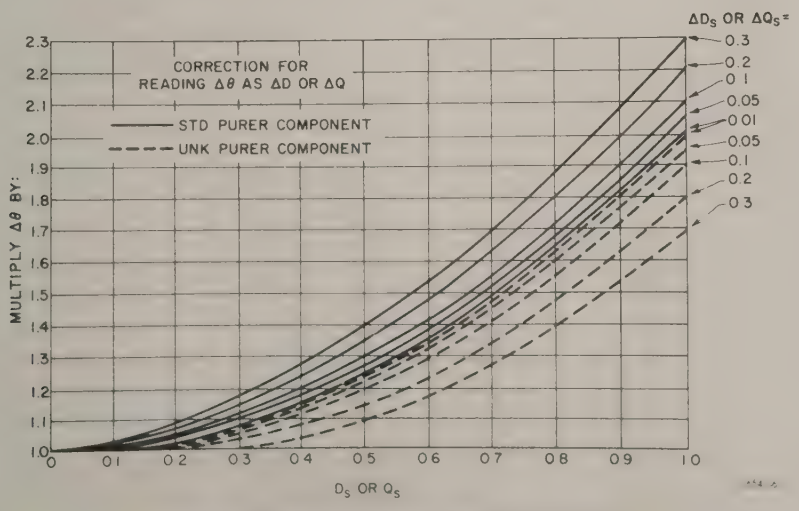

Figure 3-9. Correction factor to obtain D or Q from θ.

3.16 MEASUREMENT OF ΔD and ΔQ.

If D_s and D_x (or Q_s and Q_x) are both less than 0.1 and ΔZ is less than 10%, the $\Delta\theta$ meter indication may be interpreted directly as ΔD or ΔQ with negligible error.

The D and Q of the standard and unknown could be greater than 0.1 without exceeding the range of the instrument, which limits θ to 0.3 radian. If either or both D's (or Q's) is greater than 0.1, a correction should be applied. This correction is,

$$\Delta D = \Delta\theta\ (1 + D_s D_x) \text{ or } \Delta Q = \Delta\theta\ (1 + Q_s Q_x)$$

or, in terms of D_s (or Q_s) and $\Delta\theta$:

$$\Delta D = \frac{\Delta\theta\ (1 + D_s{}^2)}{1 \pm D_s \Delta\theta} \text{ or } \Delta Q = \frac{\Delta\theta\ (1 + Q_s{}^2)}{1 \pm Q_s \Delta\theta}$$

Figure 3-9 shows a plot of the correction factor necessary for a correct determination of ΔD or ΔQ. Note that there are two values for this function. Use the solid curve if the standard is the purer component, the dash-line curve if the unknown is the purer component.

The correct signs for ΔD or ΔQ measurements are given in Table 3-5. In the table, all D's and Q's are positive except the Q of a capacitive resistor (see Figure 1-5). The table also gives the signs for ΔR, ΔL, and ΔC measurements.

Special Measurements—Section 4

4.1 REMOTE MEASUREMENTS 4-1
4.2 THREE-TERMINAL IMPEDANCE MEASUREMENTS 4-1
4.3 MEASUREMENTS ON POTENTIOMETER 4-2
4.4 MEASUREMENTS ON SMALL CAPACITORS 4-4
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4.1 REMOTE MEASUREMENTS.

For many measurements, one or both of the external impedances to be measured must be at some distance from the instrument. For instance, remote positioning is often required when the unknown must be in a special jig or test chamber. The guard circuit extends the high-impedance range for remote measurements by effectively reducing the stray capacitance to ground that would be added by cable shields.

Two leads are necessary to attach the unknown component to the instrument. The effect of capacitance from the transformer lead to ground is negligible (refer to paragraph 3.14), and this lead, because of its low impedance, is relatively insensitive to pickup, although a shield may be necessary in some cases. The common lead is at high impedance if the unknown impedance is high, and a shield should be used to prevent pickup and to remove the capacitance between the two leads, which would otherwise shunt the unknown. If this shield were grounded, the capacitance from the common lead to ground would increase the input capacitance and greatly reduce the impedance range (refer to paragraph 3.11). Connection of this shield to the guard point and use of the instrument in the GUARDED position effectively reduces the added capacitance by a factor of about 1000, permitting use of a rather long cable with only a slight addition to input capacitance.

The guard point is the outer conductors of the two common GR874 connectors on the input connections. Thus, shielded leads using GR874 connectors can be plugged directly into the instrument.

4.2 THREE-TERMINAL IMPEDANCE MEASUREMENTS.

4.2.1 Null Method.

When it is necessary to measure the impedance or admittance between two terminals, each of which has finite impedance to a third terminal (A, Figure 4-1), it is possible to use the instrument as a null device in order to make the effect of the other two impedances (Z_a and Z_b) negligible. In a conventional bridge, it is possible to remove the effect of one of these impedances by putting it across the source or detector. The other impedance, however, is left across one arm of the bridge where it will usually cause an error. This type of measurement is possible on the 1654 if a variable standard is used (see Figure 4-2).

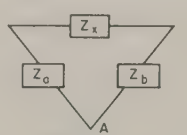

Figure 4-1. Three-terminal unknown.

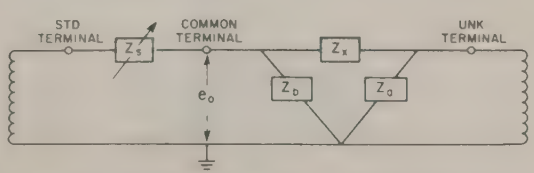

Figure 4-2. Direct impedance measurement using a variable standard.

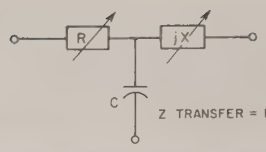

Figure 4-3. Possible error when series-connected variable standards are used.

Because impedance shunting one transformer winding has so little effect (refer to paragraph 3.14), one of the unwanted impedances (Z_a) may usually be placed across it with negligible error. This puts the other unwanted impedance, Z_b, across the detector. If the detector is nulled (both meters reading zero) by variation of the standard, Z_b has no effect on the balance conditions, although it does reduce the sensitivity of the detector. The value of the unknown at null is, of course, equal to that of the standard and can be measured in terms of impedance or admittance.

In general, the standard should consist of two adjustable components for a balance of both magnitude and phase. These components may be in series or parallel. If series variable components are used to make both the real and imaginary components of the standard adjustable, care should be taken to keep the capacitance from the junction to ground as small as possible, since this capacitance can cause a large error. Figure 4-3 shows an example.

4.2.2 Guard Point For Three-Terminal Measurements.

If the guard circuit could have zero output impedance and a gain of unity, the third terminal (A, Figure 4-1) could be connected to the guard point, and the effect of Z_a and Z_b would be negligible on the measurement, unless Z_a were so small as to load the transformer (refer to paragraph 3.14). But these ideal conditions are never met; the output impedance is finite and the gain slightly less than one. However, under certain conditions, this use of the guard terminal works well.

If point A is grounded, the reading is:

$$\frac{\dfrac{Z_x - Z_s}{Z_s}}{1 + \dfrac{Z_s}{2Z_b}}$$

If the guard circuit is used, the reading is approximately:

$$\frac{\dfrac{Z_x - Z_s}{Z_s} + \dfrac{Z_o Z_s}{Z_a Z_b}}{1 + \dfrac{Z_s (1 - K)}{2Z_b} + \dfrac{Z_o Z_s}{2Z_a Z_b}}$$

where: Z_o = output impedance of guard circuit $\approx 1\ \Omega$ in series with 1 μF.

K = guard circuit gain $\approx$0.999 at 1 kHz.

Use of the guard circuit adds a fixed error (in the numerator) that is small if Z_o is small, but this use reduces the percent error in the denominator. Thus, if Z_b is much greater than Z_s, it may be best to ground point A, since the error may be small. In this instance, Z_a should be the lower of the two stray impedances. The effects of Z_b on attenuation and phase shift can be calculated as described in paragraph 3.11, since Z_b just increases the detector input admittance.

If Z_s, Z_a, and Z_b are of the same order of magnitude (so that Z_s/Z_b is not small), and they are large compared with Z_o, it is desirable to use the guard point. This is especially true if the deviations, ΔZ and $\Delta\theta$, are large so that the fixed error, $Z_o Z_s / Z_a Z_b$, is negligible.

This guard method is most useful when small direct capacitors are to be measured and the impedances Z_a and Z_b are just stray capacitance.

4.3 MEASUREMENTS ON POTENTIOMETERS.

4.3.1 Ganged Potentiometers Used As Rheostats.

If potentiometers are to be checked as two-terminal variable resistors, several different types of indications are possible. The simplest setup is that shown in Figure 4-4, where the indication is:

$$\frac{R_x - R_s}{R_s}$$

This indication will become very large near the low end of the potentiometers and therefore is not a very realistic way to compare or to specify potentiometers. A common way of specifying potentiometers is to allow a fixed error, $\pm R_A$, plus a percent error, ±B%. This could also be expressed as ±A% of R_{max}, ±B% of R, where:

$$\frac{R_A}{R_{max}} \times 100\% = A\%$$

If the standard is a perfect potentiometer, the measurement can be set up so that this combined tolerance limit becomes a fixed meter indication. Figure 4-5 shows the setup.

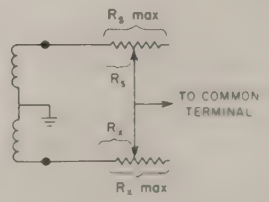

Figure 4-4. Setup for comparison of rheostats.

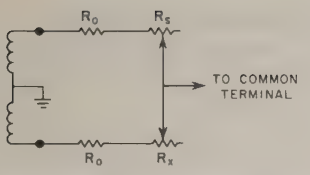

Figure 4-5. Preferred setup for comparison of rheostats.

If $R_o = \frac{A}{B} R_{max}$, a ΔZ meter indication of B% will be the allowable limit for any value of R.

Example: To compare a 1000-Ω potentiomerer, whose specifications are ±1% ±2 Ω, to a "perfect" standard 1000-Ω potentiometer:

$$R_A = 2\ \Omega \qquad A = \frac{2}{1000} = 0.002 = 0.2\% \qquad B = 0.01 = 1\%$$

$$R_o = \frac{A}{B} R_{max} = \frac{0.002}{0.01} \times 1000 = 200\ \Omega$$

The tolerance on the meters is a 1% indication. At the low end of the potentiometer, the 2-Ω fixed error is important and $\frac{2\Omega}{R_o} = 1\%$. At the high end, the allowable error is 1% + 2 Ω = 12 Ω, which is 1% of the total resistance.

4.3.2 Standard Independent Linearity.

The standard independent linearity of a potentiometer is the tolerance indicating the allowable deviation from linearity expressed as a percent of the maximum value of the potentiometer. This specification is independent of the maximum value of the potentiometer. Thus, if the deviation from linearity at any point is 8%, the resistance at that point is:

$$R = \theta R_{max} + \delta\%\ R_{max}$$

where θ is the normalized rotation.
Therefore:

$$\frac{R}{R_{max}} = \theta + \delta\% = \frac{e_o}{e_{in}}$$

See Figure 4-6.

This quantity can be measured with the setup of Figure 4-7. If the standard potentiometer is linear, the ΔZ meter will read δ%.

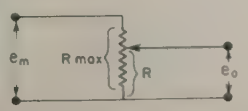

Figure 4-6. Potentiometer used as a divider.

The unknown potentiometer can also be compared with a voltage divider if a dial is used on the unknown to set the angle correctly. This is a point-by-point procedure, but could be more precise if the voltage divider were of high accuracy, such as the GR 1455 Decade Voltage Divider.

An electronic adder circuit is particularly useful for this measurement. Such a circuit makes it possible to compare potentiometers of different resistances because the output impedance of the potentiometer will have no effect.

4.3.3 Phase Shift of Potentiometers.

The comparison of phase angle of potentiometers used as two-terminal, variable resistors is a straightforward impedance-difference measurement. The phase-shift difference between two potentiometers can be measured, or a potentiometer can be compared with a fixed resistor. When small phase shifts of large potentiometers are measured, the input capacitance to the 1654 can become large, due to the connections necessary. It is desirable and simple to adjust the ΔZ meter for a null in order to reduce the error in reading $\Delta\theta$ due to this input capacitance. With a ΔZ indication of zero, the input phase-shift error (B) has no effect [$\Delta\theta_T = \Delta\theta_A\ (1 + A) + B\ \Delta Z_A$, refer to paragraph 3.11].

The measurement of voltage phase shift of a potentiometer is a voltage-transfer-ratio measurement (the setup is shown in Figure 4-7). The unknown potentiometer can be compared with a standard potentiometer of known phase shift, or with a fixed voltage divider of small or known phase shift.

If $\frac{E_o}{E_{in}}$ of the unknown potentiometer = $\mu_x = \mu_{rx} + j\mu_{ix}$

and $\frac{E_o}{E_{in}}$ of the standard potentiometer = $\mu_s = \mu_{rs} + j\mu_{is}$

the $\Delta\theta$ meter will read: $\mu_{ix} - \mu_{is}$, where μ is the open-circuit voltage gain.

If the ΔZ meter is nulled and μ_{rs} (the real part of the attenuation) is known, then the difference in phase shift is:

$$\Delta\theta = \tan^{-1} \frac{\mu_{ix} - \mu_{is}}{\mu_{rs}} \approx \frac{\mu_{ix} - \mu_{is}}{\mu_{rs}} \quad \text{if } \theta \text{ is small.}$$

If a fixed divider is used, μ_{is} can be very small, and μ_{ix} read directly. Note that high-precision divider is not necessary.

An electronic adder is desirable to reduce possible errors. Care should be taken not to add capacitance on the outputs of the potentiometers.

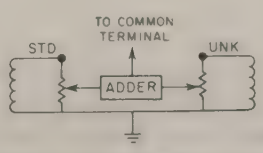

Figure 4-7. Setup for measurement of standard independent linearity or phase shift.

4.4 MEASUREMENTS ON SMALL CAPACITORS.

4.4.1 General.

The high-impedance limitation resulting from input impedance shunting the common input terminal to ground can usually be avoided by correct choice of test frequency. In the measurement of small capacitors, the phase-shift error B (refer to paragraph 3.11) can be avoided by the use of a high frequency, but the attenuation error, A, always causes difficulty as the compared capacitors approach the value of the input capacitance. This input capacitance also includes any capacitance to ground from the leads connecting the components to the "common" terminals. Therefore these leads should be short and their shields connected to the guard potential, if possible.

Shields are usually necessary to reduce hum pickup that can overload the amplifier and cause an offscale indication. The instrument, as well as nearby equipment and the operator, should be grounded.

The following paragraphs describe different methods that can be used for these low-capacitance measurements.

4.4.2 Correction For Input Capacitance Effects.

The indicated percent capacitance difference can be multiplied by

$$\frac{C_x + C_s + C_{in}}{C_x + C_s} \approx \frac{2C_s + C_{in}}{2C_s} = 1 + \frac{C_{in}}{2C_s}$$

to determine the correct ΔC%. The main difficulty is in determining C_{in} accurately enough to obtain the required precision. In the GUARDED position, this input capacitance is about 1 pF when measured at the common input terminal to the instrument. If any leads are tied to these terminals, the capacitance is increased.

One way of measuring input capacitance is shown in Figure 4-8. An error signal is produced by large capacitors C_1 and C_2 (Figure 4-8a), where $C_2 > 20C_1$. A known small capacitor, C_3, is then put on the input lead (Figure 4-8b). The ratio of the two indications is $\frac{C_3}{C_3 + C_{in}}$

$$\frac{C_1}{C_1 + C_2 + C_{in}} \quad \text{(Figure 4-8a)}$$

$$\frac{\frac{C_3}{C_3 + C_{in}} \times \frac{C_1}{C_1 + C_2}}{\frac{C_1}{C_1 + C_2 + C_{in}}} = \frac{C_3}{C_3 + C_{in}} \quad \text{(Figure 4-8b).}$$

Another way of measuring input capacitance is to compare two known capacitors and calculate C_{in}:

The advantage of this method is that the connections for calibrating and the desired measurements can be identical in order to keep C_{in} constant.

4.4.3 Measurement of ΔC In pF.

When very small capacitors are measured, the indication will be:

$$\frac{2\Delta C}{C_x + C_s + C_{in}} \approx \frac{2\Delta C}{C_{in}}$$

If C_{in} is known, the indication will be a factor times ΔC. This gives the difference in terms of the capacitance difference in pF, rather than in percent. If capacitance is added to C_{in} this type of indication will be available at higher capacitance levels. With no added capacitance, C_{in} is about 1 pF, which would result in a ΔZ reading of 0.02% to indicate a ΔC of 0.0001 pF. Since this sensitivity is not often required, it is desirable to increase C_{in} with known capacitance so that C_{in} is more accurately known; the above equation is more nearly correct and hum pickup is reduced.

Another useful method for measuring small capacitance involves the use of an adjustable capacitor, C_a, connected from the common terminals to ground (see Figure 4-9), so that:

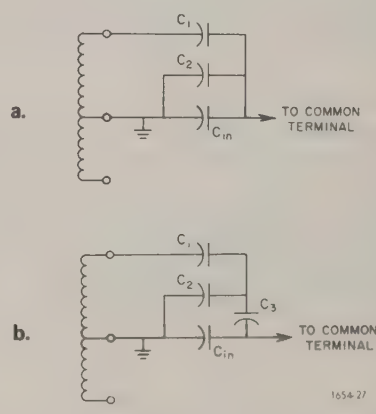

Figure 4-8. Measurement of detector input capacitance.

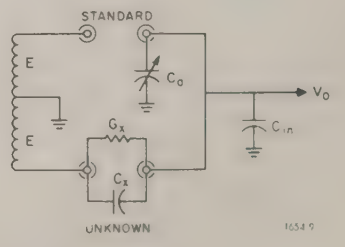

Figure 4-9. Measurement of small capacitance using an adjustable capacitor connected from the common (standard) terminal to ground.

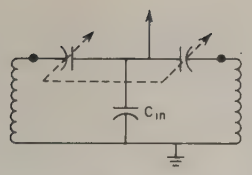

Figure 4-10. Comparison of ganged capacitors.

$$\frac{V_o}{E} = 2\left[\frac{C_x}{C_x + C_a + C_{in}}\right] 100\%$$

where E = bridge transformer voltage

V_o = bridge-output voltage proportional to C_x

$C_{in} \approx 1$ pF, with the INPUT switch in the GUARDED position

$C_a \geqslant 10\ C_x$

then: $\frac{V_o}{E} = \frac{2C_x}{C_a + C_{in}}$

Example: assuming $C_x \leqslant 10$ pF, calibrate by connecting a known 10 pF capacitor to the UNKNOWN terminals and adjust $C_a \approx 200$ pF to obtain a reading of 10.00 on the MAGNITUDE DIFFERENCE meter. Subsequent unknown capacitors will give readings directly in pF. The $\Delta\theta$ reading will indicate $-\frac{2G_x}{\omega C_a}$.

4.5 MEASUREMENTS ON GANGED CAPACITORS.

Measurements on ganged capacitors are straightforward in principle, but such difficulties as pickup and input capacitance require special care. The simple connection would give an indication of ΔC in percent, although a correction for C_{in} may be necessary if the minimum value of C is small. Capacitor specifications are often given as $\pm C_a$ pF ±B%, which is analagous to the potentiometer specification in paragraph 4.3. This complex tolerance can be made to give a constant meter indication by increasing the input capacitance with added fixed capacitors. This setup is shown in Figure 4-10. The tolerance limit will be an indication of B% regardless of capacitor setting if:

$$C_{in} = \frac{2C_a}{B}\ (100).$$

Example: Two 1000-pF ganged capacitors should track to ±2 pF ±1%.

$$C_A = 2\text{ pF} \qquad B = 1\%$$

$$C_{in} = \frac{2C_A(100)}{B} = \frac{2\ (2\text{ pF})\ (100)}{1\%} = 400\text{ pF}$$

A reading of 1% will show the tolerance limit. At 100 pF, the maximum allowable difference is:

$$\frac{1}{100} \times 100\text{ pF} + 2\text{ pF} = 3\text{ pF}.$$

$$\Delta Z = \frac{\Delta C_{max}}{\frac{C_x + C_s + C_{in}}{2}} = \frac{3}{\frac{100 + 100 + 400}{2}} = \frac{3}{300} = 1\%$$

At 1000 pF; the maximum allowable difference is:

$$\frac{1}{100} \times 1000\text{ pF} + 2\text{ pF} = 12\text{ pF}.$$

$$\Delta Z = \frac{\Delta C_{max}}{\frac{C_x + C_s + C_{in}}{2}} = \frac{12}{1200} = 1\%$$

4.6 SMALL DISSIPATION-FACTOR CAPACITORS.

When the dissipation factor of small capacitors is measured, a large ΔZ reading can result in an error caused by input-capacitance phase shift, as well as other errors (refer to paragraph 3.11). If the ΔZ meter is nulled, these difficulties are removed. If the capacitor is very small, there is also an attenuation error (A) requiring correction. One setup that has been used to measure very small values of D is shown in Figure 4-11.

In the setup shown, the component to be tested is plugged into the unknown terminals. The variable capacitor is balanced for a null on the ΔZ meter. The unknown quantity is read directly on the variable capacitor and the dissipation factor is read on the $\Delta\theta$ meter.

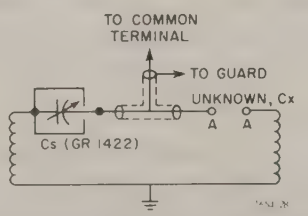

Figure 4-11. Measurement of small dissipation factors.

4.7 DIELECTRIC SAMPLE MEASUREMENTS.

4.7.1 General.

The high sensitivity of the 1654 makes it useful for measurements on dielectric samples. The direct indication of D on the $\Delta\theta$ meter can greatly speed up dissipation-factor measurements that ordinarily require a precise D balance, and the ΔZ sensitivity and sign indication speed up the capacitance balance necessary for measurement of dielectric constant.

For precise measurement of both of these quantities on solid dielectric samples, the GR 1690 Dielectric Sample Holder is recommended. D measurements are possible without such a holder, simply make a capacitor out of the sample by applying aluminum foil to each side and compare it with a standard capacitor to determine the value of D. However, for precise D values, stray losses and stray capacitances must be controlled; a difficult task without a precision sample holder. A recommended setup for both K and D measurements is shown in Figure 4.12.

The measurement procedure is similar to that described in the 1690-A Dielectric Sample Holder instruction book. It is repeated below, using the same terminology except that the D indication becomes a $\Delta\theta$ reading. The 1690-A instruction book should be studied carefully for familiarization with the measurements.

4.7.2 Procedure.

a. Set up the equipment as shown in Figure 4.12. Use the GUARDED position.

b. Insert the sample in the holder and screw the top electrode down until it is firmly in contact, as indicated by the release of the drive mechanism.

c. Balance C_s, until the ΔZ meter reads zero, and record the reading of C_s as C_1. Record the $\Delta\theta$ meter indication ($\Delta\theta_1$) and the spacing of the electrodes (t_1).

d. Remove the sample from the holder. Rebalance the ΔZ meter for zero reading by readjusting the micrometer capacitor (electrodes). Do not disturb the value of C_s.

e. Record the new spacing (t_2) and the new reading on the $\Delta\theta$ meter ($\Delta\theta_2$).

4.7.3 Calculation.

The calculation of K and D is the same as that given in the 1690-A instruction book, except that $\Delta\theta_1$ and $\Delta\theta_2$ replace D_1 and D_2.

4.7.4 Precautions.

The input impedance of the 1654 comparator can cause errors, as described in paragraph 3.11. However, if ΔZ is balanced to zero, the error due to R_{in} is greatly reduced. At low frequencies, the ΔZ balance must be very precise since the factor B (refer to paragraph 3.11) is large. The factor A will cause an error if the capacitance of the unknown is small, in which event, the calculated D_x should be multiplied by $1 + A = 1 + \frac{C_{in}}{2C_x}$ for the correct value. Here C_{in} is the input capacitance of the bridge (refer to paragraph 4.4.2). This error is kept to a minimum by the use of shields tied to the guard terminal.

A small error in determining C_x is possible, due to the effect of the D on the ΔZ balance. There are two sources of error here. First, because the magnitude $|Z|$ is larger than the reactance

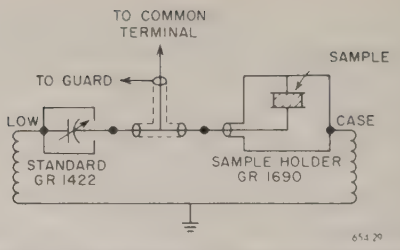

Figure 4-12. Measurement of dielectric samples using the 1690 Dielectric Sample Holder.

$$\frac{1}{\omega C} \quad |Z| = \frac{1}{\omega C}\sqrt{1 + D^2}$$

there is a small error if D is not zero. However, the error is less than 0.01% if D is less than 0.01. A second source of error is the factor B, which results in a ΔZ error and therefore an error in the indication C_1 when ΔZ is set to zero. The reading C_1 is in error by $B\Delta\theta$ times 100%. Since $\Delta\theta_1$ is approximately D_x, this error depends on C_x, D_x, and the frequency, and is usually negligible at 1 kHz or higher.

Measurements at 100 Hz are difficult because of the phase shift errors due to B, and also the presence of hum, which makes precise meter indications difficult.

4.8 BALANCED TRANSFORMER WINDINGS.

The instrument compares two impedances, but if these two components are coils wound on the same core and connected properly, the ΔZ meter will read approximately $\frac{\Delta N}{N} \times 100\%$ when ΔN is the turns difference and N is the average number of turns ($\frac{N_x + N_s}{2}$). The accuracy with which this quantity is indicated depends upon the Q of the inductors and the coefficient of coupling. However, it is usually sufficient to indicate an unbalance as long as the Q's of the two windings are about the same. Turns may then be added to bring the windings into balance.

The actual indications are given below for the setup of Figure 4-13.

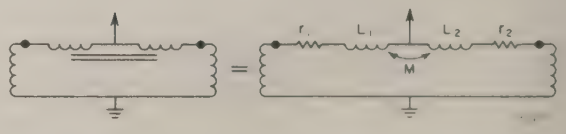

Figure 4-13. Measurements of balanced transformer windings.

$$\Delta Z \text{ reads } 2\,\frac{\dfrac{L_1 - L_2}{L_1 + L_2 + 2M} + \dfrac{r_1^2 - r_2^2}{\omega^2 (L_1 + L_2 + 2M)^2}}{1 + \dfrac{(r_1 + r_2)^2}{\omega^2 (L_1 + L_2 + 2M)^2}}$$

If $r_1 \approx r_2$ and $\frac{r}{\omega L}$ is small:

$$\Delta Z \text{ reads } \frac{\dfrac{L_1 - L_2}{L_1 + L_2 + 2M}}{2}$$

If $K = \frac{M}{\sqrt{L_1 L_2}} \approx 1$ (good coupling)

$$\Delta Z \text{ reads } \frac{\dfrac{L_1 - L_2}{L_1 + L_2 + 2\sqrt{L_1 L_2}}}{2} = \frac{\dfrac{\sqrt{L_1} - \sqrt{L_2}}{\sqrt{L_1} + \sqrt{L_2}}}{2}$$

If $L \sim N^2$

$$\Delta Z \text{ reads } \frac{\dfrac{N_1 - N_2}{N_1 + N_2}}{2} = \frac{\Delta N}{N_{avg}}$$

4.9 MEASUREMENTS WITH DC POWER.

4.9.1 General.

This instrument is not particularly suited for the comparison of components with applied dc voltage or current. However, since this type of measurement must often be made, the following paragraphs describe possible test setups and the difficulties involved.

The errors caused by the components added to apply the direct current should be independent of the value of the dc, so that the readings taken with the applied source set at zero could be considered initial balances and subtracted from the test readings.

4.9.2. Dc Power Requirements.

The dc power supply used in the measurement setups in Figures 4-14 thru 4-19 should meet the following requirements:

VOLTAGE. 0 to 400 V, dc.

CURRENT. The maximum instantaneous current must be limited to 100 mA to prevent the bridge from being severely damaged if the unknown is shorted. Many available power supplies use a capacitor across the output terminals to reduce the output impedance; power supplies of this type should not be used because the capacitor can cause instantaneous surges of current in excess of 100 mA. Therefore, the power supply must be electronically regulated to prevent excessive surges of current and the output terminals must be free of any capacitive filter components.

IMPEDANCE. The impedance of the power supply must be much smaller than the impedance of the unknown. The output impedance of the power supply is in series with the unknown, except when both the standard and the unknown capacitors are biased.

REFERENCE. The power supply must have grounding or floating capabilities. This requirement will depend on the bias setup used.

4.9.3 Biasing Standard And Unknown Capacitors.

The measurement setup for using external bias (E_{dc}) applied to both the standard and the unknown capacitor is shown in Figure 4-14.

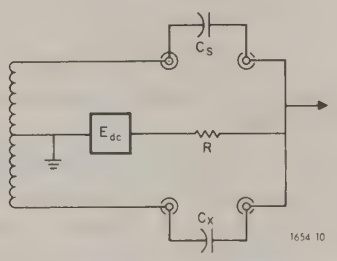

Figure 4-14. External bias (E_{dc}) applied to standard and unknown capacitors.

The resistor, R, shunts the input circuit and can cause a $\Delta\theta$ error, the same error caused by the input resistance (refer to paragraph 3.11), except that the error factor becomes $\frac{1}{2\omega C_s R}$ However, if the capacitors have low leakage, R can be very large and the $\Delta\theta$ error can be negligible. The maximum voltage that is applied to the common terminals is 400 V.

4.9.4 Biasing Unknown Capacitor.

The measurement setup for using external bias (E_{dc}) applied only to the unknown capacitor is shown in Figure 4-15.

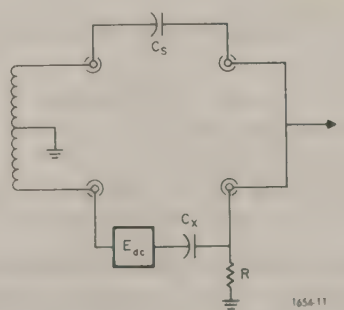

Figure 4-15. External bias (E_{dc}) applied to unknown capacitor only.

As in the setup shown in Figure 4-14, the resistor, R, shunts the input current and can cause a $\Delta\theta$ error. If the capacitor has low leakage, R can be very large and the $\Delta\theta$ error will be negligible.

Impedance of the bias supply should be very small compared to the impedance of the unknown.

4.9.5 Biasing Standard And Unknown Resistors.

The measurement setup for applying bias voltage to both the standard and the unknown resistors is shown in Figure 4-16.

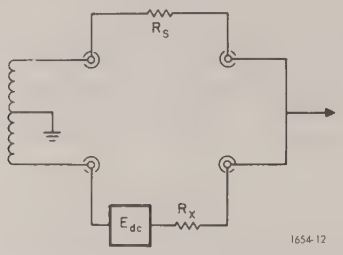

Figure 4-16. External bias (E_{dc}) applied to standard and unknown resistors.

The applied voltage is divided between R_s and R_x so that the actual voltage across each component should be measured if the component values differ by an appreciable amount. The maximum current through the standard and unknown resistors should be less than 100 mA.

4.9.6. Biasing Unknown Resistor.

See Figure 4-17 for the measurement setup used for applying bias voltage to the unknown resistor only.

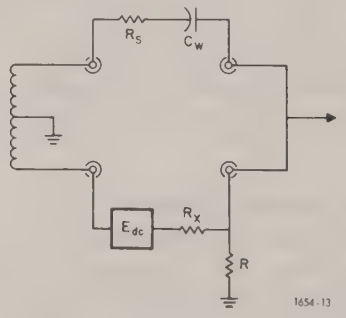

Figure 4-17. External bias (E_{dc}) applied to unknown resistor only.

The resistor, R, causes a voltage division that results in a lower voltage across the unknown, but the resultant error is easy to correct. The MAGNITUDE DIFFERENCE reading can be multiplied by $1 + R_s/2R$ to make the correction. The capacitor, C_W, should be as large as possible.

4.9.7 Biasing Standard And Unknown Inductors.

The measurement setup for application of the bias voltage to both the standard and the unknown inductors is shown in Figure 4-18.

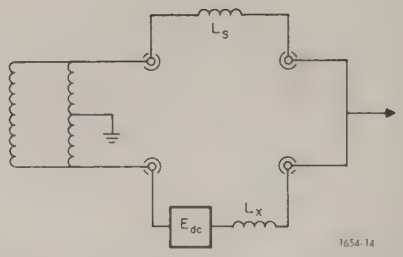

Figure 4-18. External bias (E_{dc}) applied to standard and unknown inductors.

The current through the standard and the unknown also flows through the driver-transformer secondary winding, as well as the bridge ratio transformer, and it should be limited to 100 mA. This current can cause a small error at 100 Hz if small $\Delta\theta$ values are measured when large ΔZ values exist. This error is a result of distortion in the transformers.

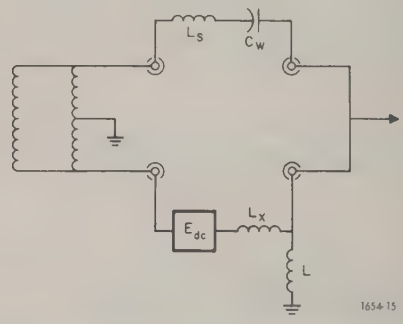

Figure 4-19. External bias (E_{dc}) applied to unknown inductor only.

4.9.8 Biasing Unknown Inductor.

See Figure 4-19 for the measurement setup used for applying bias voltage to the unknown inductor only.

The dc path across the detector input will cause some error unless L is very large. A large capacitor, Cw, is also recommended.

4.10 OUTPUT FACILITIES.

Analog output voltages proportional to meter deflections are available at the rear of the instrument (refer to Table 1-2 and Figure 1-3). The output of the 1654 can be used for digital readout, dc recording, and manual and automatic sorting (see Figure 4-20).

4.10.1 Digital Readout.

Although accuracy to 30 ppm is adequate for most uses, there are always applications where increased sensitivity is desired. Higher resolution of better than 10 ppm can be obtained when the output is measured by a digital voltmeter. The DVM used to measure the ANALOG VOLT-

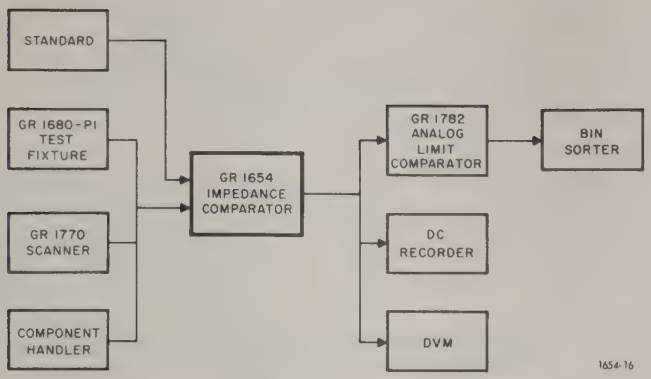

Figure 4-20. Typical instruments and devices for an automatic component-measurement system.

AGE OUTPUT should have an input impedance larger than 10 MΩ and full-scale ranges of 3.00 V and 10.00 V. For example, for a magnitude difference of 1%, the DVM will indicate 10.00 V with a resolution of 10 ppm.

4.10.2 Analog Recording.

In applications, such as temperature-coefficient measurements, a permanent record of the test data is desirable. In such measurements, the analog output voltages of 3-V and 10-V full scale, behind a 2-kΩ source impedance, can be used to drive dc recorders, such as the GR 1522.

4.10.3 High-Speed Sorting.

The 1654 can be used to advantage in manual, semi-automatic, or fully-automatic selection and sorting applications.

For manual sorting, the large panel meters reduce errors and fatigue. For faster and relatively error-free sorting, use the analog output voltages available on the rear panel. The 1782 Analog Limit comparator is used to compare these voltages with preset upper and lower limits. For manual sorting, GO or NO GO lights indicate if the component is within acceptable limits. For automatic sorting, relay contacts are available to operate automatic sorting and classifying mechanisms. A rate of up to four tests per second can be obtained from this system.

The 1782 can accept up to two inputs simultaneously in the form of analog voltages from 0 to ±10 V. For example, one input is the magnitude difference and the other the phase-angle difference. The source resistance of the input should be less than 100 Ω.

Decision outputs are provided by front-panel lamps with optional corresponding internal SPDT relays. For visual indication, one NO GO lamp is used for each of the four limits and a single GO lamp to indicate that measurement is within all limits. In addition, the analog-input voltages are available at the analog voltage-output connector to drive additional analog limit comparators if required. Two cascaded 1782's will give four sets of limits, etc.

The schematic diagram of the 1782 Analog Limit Comparator is shown in Figure 4-21. The method of comparison is shown in Figure 4-22.

For each independent limit, the input voltage, E , is compared with preset voltage, E_2. The unbalance voltage, E_o (if any), is amplified by an operational amplifier with sufficient positive feedback to cause the amplifier to switch off and on. Its output drives the NO GO lamp drivers. If the

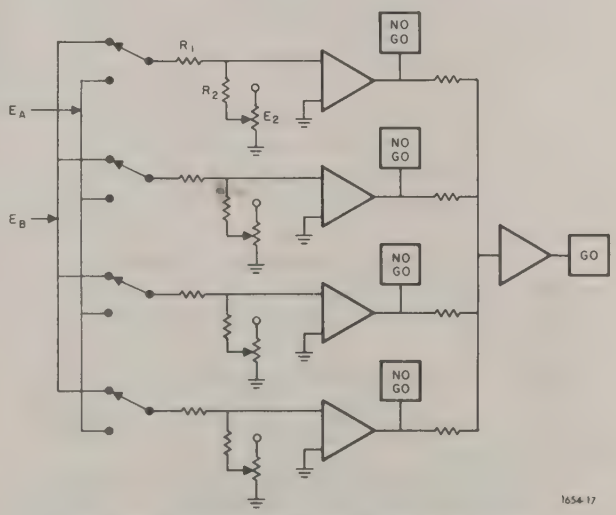

Figure 4-21. Schematic diagram of 1782 Analog Limit Comparator.

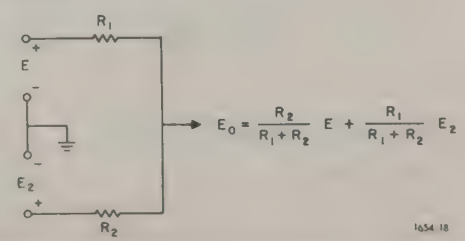

Figure 4-22. Comparison of input signal (E) with preset voltage (E_2) in 1782.

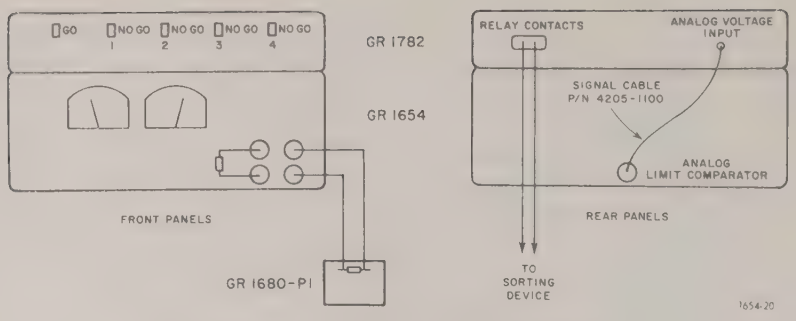

Figure 4-23. Typical test setup for high-speed selection and sorting of R, L, and C components.

comparison is out of tolerance, the NO GO lamps will be ON. Otherwise, a GO indication is given if the comparison is within all preset limits. A typical 1654/1782 sorting system is shown in Figure 4-23.

4.11 THREE-TERMINAL CAPACITORS.

The shield of a three-terminal capacitor, such as the GR 1422-CB, can be connected either to guard (refer to paragraph 3.7) or to ground. Both connections cause an error when small capacitors are measured and the error resulting from each connection should be evaluated to see which is smaller.

If the shield is guarded, there is a fixed error of $\frac{C_a C_b}{C_s C_o} \times$ 100% where C_o (the output capacitance of the guard) is 1 μF and C_a, C_b, and C_s are as shown in Figure 4-24. This error *is not* a percent of the reading, but rather a constant-error term that is present no matter what the capacitance difference.

If the shield is tied to ground, the capacitance, C_b, is added to the detector input capacitance, C_{in}, thus increasing the error. The resulting magnitude error, when capacitors are measured, is approximately $\frac{C_{in} + C_b}{C_x + C_s} \times$ 100%. This *is* a percent of the reading and is therefore negligible, if only 1% or less.

In either arrangement, the shield of the lead connecting the capacitor to the common terminal should be tied to guard and the shield of the other lead (to the STANDARD or UNKNOWN terminal) should be grounded, if shielded wire is used. Note that these shields are not joined. Also, if the capacitor shield is guarded, it must be insulated from ground.

4.12 SEMICONDUCTOR CAPACITANCE AND CONDUCTANCE.

The 1654 can be used for production checking of small capacitance and conductance values of back-biased diodes and transistor collector junctions. The basic circuit is shown in Figure 4-25. The resistor, R_{in}, shunts the input of the 1654 detector, causing a large attenuation in the signal. If R_{in} is small compared to the impedance of the diode, then the 1654 will read:

$$\Delta Z \text{ meter reading} \approx 2\ GR_{in}$$

$$\Delta\theta \text{ meter reading} \approx 2\ \omega CR_{in}$$

where G and C are the equivalent parallel conductance and capacitance of the diode or transistor being tested.

For example, if R_{in} = 500 Ω, the ΔZ meter will read 10 μV full scale on the 1% range and the $\Delta\theta$ meter will read 15.9 pF full scale on the 0.1 radian range at 100 kHz.

If impedance is connected between the standard terminal and the common terminal, the meters will read the difference in capacitance and conductance. A variable capacitance is shown, which is useful in cancelling out the capacitance of the leads and any test fixture used.

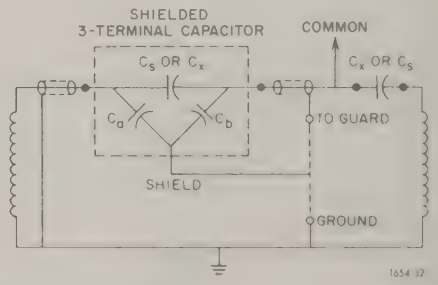

Figure 4-24. Measurement of shielded, three-terminal capacitors.

Figure 4-25. Measurement of back-biased diode and transistor capacitance and conductance.

Theory–Section 5

5.1 GENERAL 5-1
5.2 OSCILLATOR/POWER AMPLIFIER 5-2
5.3 BRIDGE CIRCUIT 5-3
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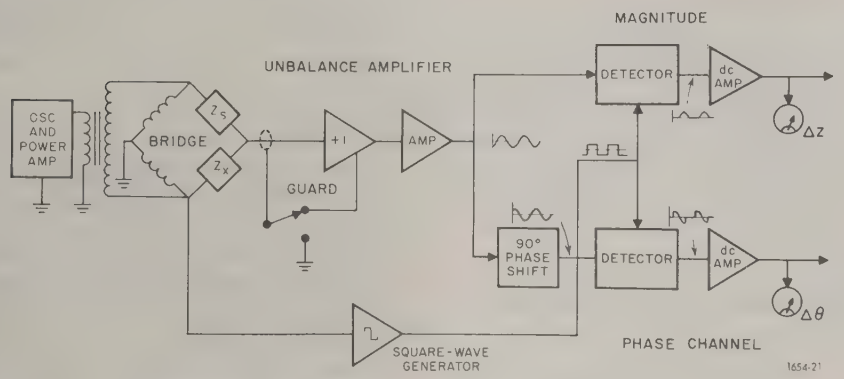

Figure 5-1. Block diagram of 1654 Impedance Comparator.

5.1 GENERAL.

The block diagram (see Figure 5-1) of the 1654 Impedance Comparator indicates the various operations necessary to produce a measurement signal and provide two meter indications, as well as the analog output voltage available at the rear of the instrument.

An internal RC oscillator generates the power frequencies of 100 Hz, 1 kHz, 10 kHz, and 100 kHz. Its output is fed to a power amplifier that drives the bridge transformer. The bridge circuit consists of the two windings of a tightly coupled 1:1-ratio torodial transformer with the standard and unknown impedances serving as the two remaining bridge arms.

The unbalance voltage of the bridge, a measure of the magnitude difference and phase-angle difference between the standard and unknown, is applied to a high input-impedance amplifier so that no loading will occur when measuring high-impedance components.

In the case of high-impedance measurements, where shielded cable is used to prevent pickup, the cable capacitance to ground will cause phase shift and attenuation of the unbalance signal. The amplifier also provides a low-impedance guard voltage that can be used to drive the amplifier input shield at approximately the same potential as the input, to minimize cable capacitance. The guard can effectively reduce cable capacitance by a factor of about 1000. This allows measurement of test components located as far as 30 ft. away with negligible error.

After further amplification, the unbalance signal is fed directly to the phase-sensitive detector in the magnitude channel. The phase detector is essentially a switch that is synchronous with the frequency of oscillation. Exact switching is controlled by a square wave that is referenced to the zero phase signal of the bridge.

The rectified voltage is that component of the error voltage that is in phase with the controlling square-wave voltage. The detected output is fed to a low-drift dc operational amplifier that provides the required analog output voltage and the magnitude-difference meter reading.

For the phase channel, the circuitry is of identical design except that the error voltage is first applied through a 90° phase shift circuit before it reaches the phase-sensitive detector. This brings the frequency of oscillation into phase with the test component, due to the phase difference. In this channel, the indication is the phase-angle difference between the test component and the standard.

The following paragraphs present a circuit analysis and accompanying elementary schematics of the various circuit components described in paragraph 5.1. Refer also to the complete schematic diagrams in Section 7.

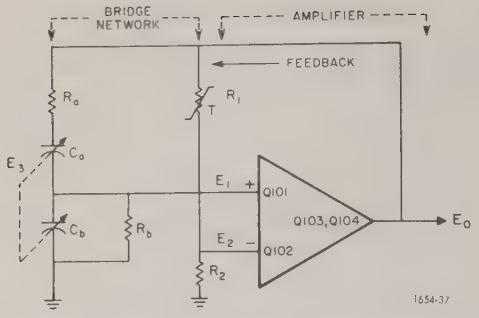

Figure 5-2. Diagram of RC Oscillator in the oscillator/ power amplifier circuit.

5.2 OSCILLATOR/POWER AMPLIFIER.

5.2.1 Oscillator.

See Figure 5-2 for a simplified block diagram of the oscillator circuit. The signal source for the measurement bridge is a Wienbridge-type RC oscillator that utilizes a thermistor (R1) for amplitude control. The oscillator circuit board is located in the OSC-PA compartment in the right rear side of the instrument. See Figure 5-3 for a more detailed layout of the bridge network.

5.2.2 Bridge Network.

A divider in the bridge network (Ra, Ca, Rb, and Cb, Figure 5-2) determines the operating frequency:

$$\omega_o = \frac{1}{\sqrt{R_a C_a R_b C_b}}$$

The ratio of the output of this divider applied to Q101 (E_1) to the voltage applied to the input of the divider (E_3), i.e. the transfer function, is:

$$\frac{E_1}{E_3} = \frac{1}{3 + j\frac{\omega}{\omega_o} - \frac{\omega_o}{\omega}} = \frac{1}{3} \text{ at the operating frequency.}$$

Another divider in the bridge network (R_1 and R_2) determines the gain of the amplifier. The ratio of the output of this divider applied to Q102 (E_2) to the voltage applied to the input of the other divider (E_3), i.e., its transfer function, is:

$$\frac{E_2}{E_3} = \frac{R_2}{R_1 + R_2} = \frac{1}{3}$$

This divider automatically preserves the amplifier gain at 3, thus holding the circuit's loop gain at 1 and maintaining stable oscillations of the circuit at a frequency of ω_o. Thermistor, R_1, maintains a constant output amplitude.

The FREQUENCY control (S905), on the front panel, determines the operating frequency, ω_o. This control selects the capacitance values for C_a and C_b (see Figure 5-2 and 5-3). Each frequency can be varied slightly by internal adjustments R111, R112, R113, and R114.

Thermistors R132 and R134 compensate for the temperature coefficients of C_a and C_b.

5.2.3 Oscillator Amplifier.

See Figure 7-4 for a schematic diagram of the oscillator amplifier. This is a four-transistor operational amplifier with Q101 and Q102 forming a differential pair whose output is taken from the collector of Q101 and fed to the base of Q103. The output of Q103 is applied to the base of Q104 (emitter follower) whose output is used as feedback to sustain oscillations in the bridge network and to drive the power amplifier which, in turn, drives the bridge circuit. At the base of Q103, R104 and C101 are utilized to maintain high-frequency stability.

5.2.4 Power Amplifier.

Figure 7-4 shows a schematic diagram of the power-amplifier circuit. The CALIBRATE control (R902) on the front panel is used to set the oscillator voltage level that is applied to the power amplifier. The power amplifier pro-

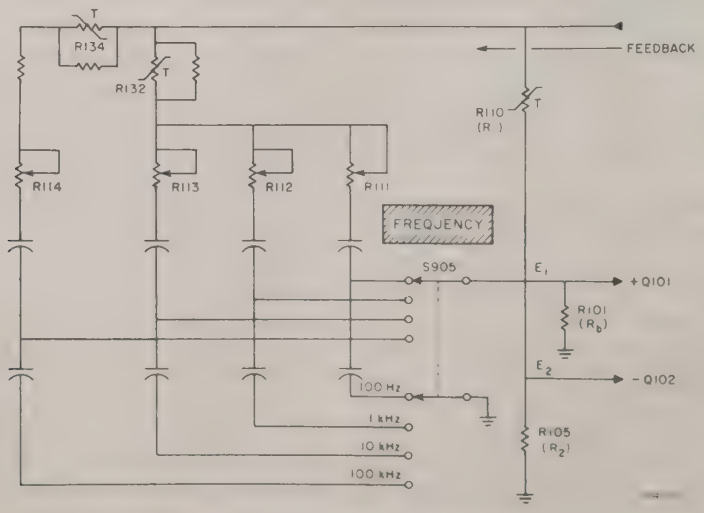

Figure 5-3. Bridge network schematic.

vides the necessary high-current signal to drive the bridge transformers.

The signal from R902 is applied to the base of Q105, the input amplifier. The emitter of Q105 is connected to the output circuit at the common-emitter junction of Q107 and Q108, thus setting the bias of Q105. Transistor Q105 detects any difference voltage between the input and output, amplifies this difference voltage, and applies it to the base of Q106, which drives the push-pull output stage (Q107 and Q108).

Capacitor C110 maintains high-frequency stability of the circuit, and C111 provides high-impedance drive for the output stage. Diodes CR101 and CR102 eliminate crossover distortion of the push-pull output stage. Diodes CR103 through CR105 are used for output-circuit protection.

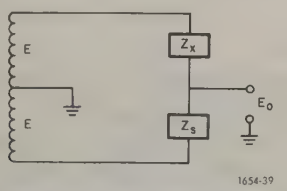

Figure 5-4. Basic bridge circuit.

5.3 BRIDGE CIRCUIT.

5.3.1 Bridge Equations.

The basic bridge circuit is shown in Figure 5-4. If the voltages (E) across the inductively coupled ratio arms are equal, the output voltage (E_o) is:

$$\frac{E_o}{E} = \frac{Z_x - Z_s}{Z_x + Z_s}$$

The real part is:

$$R_e\left(\frac{E_o}{E}\right) = \frac{\dfrac{|Z_x| - |Z_s|}{|Z_x| + |Z_s|}}{1 + \dfrac{\cos(\theta_x - \theta_s) - 1}{1 + \dfrac{|Z_x|}{2|Z_s|} + \dfrac{|Z_s|}{2|Z_x|}}}$$

If $\theta_x - \theta_s$ is small, $\cos(\theta_x - \theta_s)$ is close to unity and this equation can be reduced to:

$$R_e\left(\frac{E_o}{E}\right) \approx \frac{|Z_x| - |Z_s|}{|Z_x| + |Z_s|}$$

For $(\theta_x - \theta_s) \leq 0.1$ and $\Delta Z \leq 10\%$, this approximation is extremely reliable and will produce a maximum error of 0.25%. This error is 0.25% of the actual magnitude difference and is insignificant on all ranges. For example, when the magnitude difference is measured on the 0.1% range, the error is <0.25% x 0.1%, or 2.5 ppm.

Within the range of the bridge, $(\theta_x - \theta_s) \leq 0.3$ and $\Delta Z \leq 30\%$, the worst error is 2.2% of the actual magnitude difference.

Since it is generally desirable to measure the magnitude difference as a percent of the standard rather than the average, an additional approximation is necessary; if $(|Z_x| - |Z_s|)$ is ≤3%, then:

$$\frac{\dfrac{|Z_x| - |Z_s|}{|Z_x| + |Z_s|}}{2} \approx \frac{|Z_x| - |Z_s|}{|Z_s|}$$

which is the result desired. The error resulting from this approximation is negligible, except in the 10% and 30% ranges where the scale becomes nonlinear. Rather than complicate the meter reading by using two more scales, the magnitude channel has been linearized to ensure accurate readings without correction for deviations up to 30%.

The imaginary part of the bridge unbalance voltage is:

$$I_m\left(\frac{E_o}{E}\right) = \frac{\sin(\theta_x - \theta_s)}{\cos(\theta_x - \theta_s) + \dfrac{|Z_x|}{2|Z_s|} + \dfrac{|Z_s|}{2|Z_x|}}$$

If $\Delta Z \leq 10\%$ and $\Delta\theta \leq 0.1$ radian, this expression is reduced to:

$$I_m\left(\frac{E_o}{E}\right) = \frac{1}{2}(\theta_x - \theta_s)$$

with an error of 0.25%, which is a percent of the meter reading, and therefore, negligible.

In the worst case, for $\Delta Z = 30\%$ and $\Delta\theta \leq 0.3$ radian, the error is 0.6% of the phase-angle difference.

5.3.2 Bridge Transformers.

The bridge transformers consist of a driver transformer that provides test voltages of 0.3 V, 1 V, and 3 V to the bridge and a tightly-coupled 1:1-ratio toroidal transformer. A diagram of the driver transformer is shown in Figure 5-5.

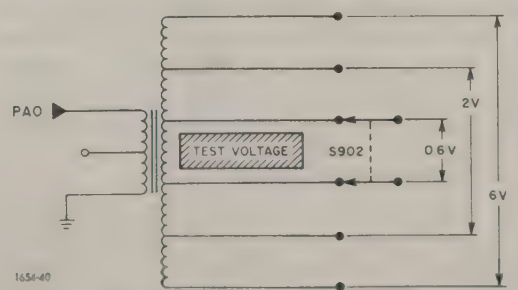

Figure 5-5. Bridge driver transformer.

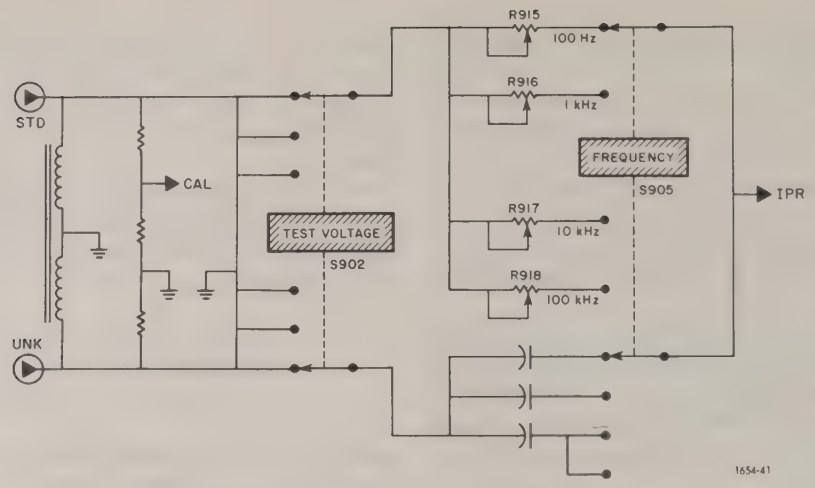

Figure 5-6. Elementary diagram of phase-converter circuit.

The TEST VOLTAGE switch (S902) on the front panel selects the test voltages that determine the measurement range. For test voltages of 0.3 V, 1 V, and 3 V, the maximum deviation ranges are ±30%, ±10%, and ±3%, respectively.

A tap on the primary winding provides a 2-V test voltage for up to ±10% deviation. This test voltage is useful for checking certain types of capacitors to military specifications, such as MIL-C-11015C.

The 1:1-ratio toroidal transformer is wound on a high-permeability, wound-ribbon core. The two windings are made by twisting two identical wires together, and then winding the twisted pair. This method approaches the ideal, where the windings occupy the same volume so that the flux linkage is identical, thus producing unity coupling and equal output voltages.

5.3.3 Z Phase Converter and CAL 1% Voltage.

The Z phase-converter circuit and CAL 1% voltage are shown in Figure 5-6. The unbalance voltage from the bridge is fed through a series of amplifier stages before it is applied to the phase-sensitive detectors (see Figure 5-1); at this point, phase errors can be expected. The reference voltage (IPR) derived from the bridge voltage is used to control the phase detectors and is brought into phase with the magnitude portion of the unbalance voltage by adjusting trimmers R915 through R918, associated with each frequency.

The junction of R924 and R925 provides a 1% unbalance calibration voltage that is inserted into the unbalance amplifier when the INPUT switch (S906) is set to CAL 1%.

5.4 UNBALANCE-AMPLIFIER.

The unbalance-amplifier circuit board, as viewed from the front of the instrument, is the first board in the center compartment. The circuit consists of a high-input-impedance amplifier, a guard circuit, two high-level signal amplifiers, and a 90°-phase-shift stage.

5.4.1 Amplifier.

An elementary schematic of the high-input-impedance amplifier circuit is shown in Figure 5-7.

The wide-band amplifier features high input impedance, unity gain, and several outputs. High input impedance is achieved by using a field-effect transistor, Q301, in a source-follower configuration. Input capacitance is reduced to a minimum through bootstrapping techniques, with capacitors C304, C305, and C306.

The error signal from the bridge circuit is applied to the gate of Q301. The output of Q301 drives two unity-gain amplifiers, the signal amplifier and the guard amplifier. The signal amplifier is made up of Q304 and Q305. The output of Q304 is used to drive Q305, whose output is used to:

1. provide an error signal for further amplification,
2. provide the necessary feedback for Q301 to increase input impedance,
3. drive the overload amplifier which drives the logic circuits,
4. provide feedback to the emitter of Q304, thus obtaining constant unity gain.

5.4.2 Guard.

The guard amplifier is made up of Q302 and Q303, see Figure 7-6. The output of Q302 drives Q303. The output of Q303 provides input guard and drives the input shield to minimize cable capacitance if shielded cables are used to connect test components to the instrument.

5.4.3 High-Level Signal Amplifiers.

Two operational amplifiers (see Figure 7-6) further amplify the error signal for use by the phase-sensitive detectors.

The first stage accepts the error signal, OVS, from the output of the unity-gain amplifier. This amplifier consists of four transistor stages, Q306 through Q309. Due to its high open-loop gain, the closed-loop gain of this amplifier is

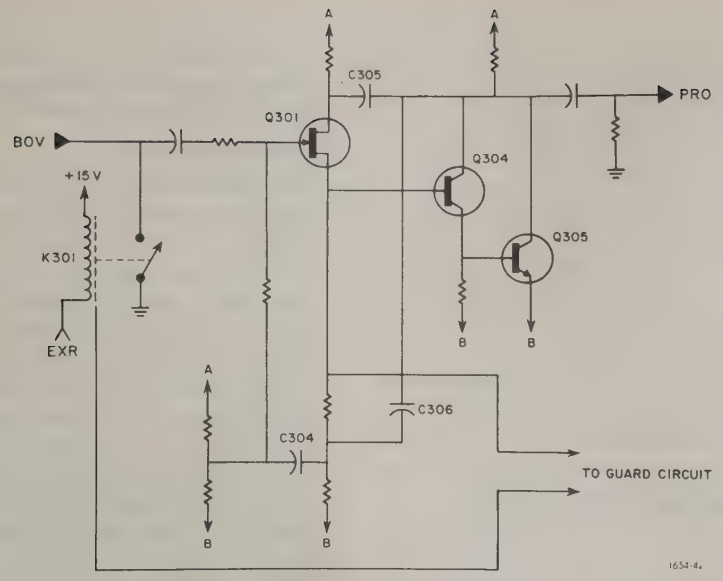

Figure 5-7. High-impedance amplifier used in the unbalance-amplifier circuit.

very nearly equal to $1+\frac{R326}{R324}$. Capacitor C321 ensures high-frequency stability. Resistor R318 provides an indication of off-scale direction when K302 is energized during overload conditions.

The second stage is another operational amplifier consisting of three transistor stages, Q310 through Q312. This amplifier provides voltage amplification with an overall gain that is approximately equal to the ratio of R332 to R331. The output signal, FOA, is fed directly to the phase-sensitive detector in the magnitude channel and to the 90% phase-shift circuit in the phase-angle difference channel. Capacitor C313 is switched into the circuit at 100 Hz to minimize phase shift through the amplifiers.

5.4.4 90° Phase Shift.

An operational amplifier consisting of four transistor stages, Q313 through Q316, is used in conjunction with the RC phase-shift circuits to provide a 90° phase shift versus frequency while maintaining unity gain over the whole frequency range (see Figure 5-8).

The open-loop gain of the operational amplifier is very large. The input/output transfer function can be written as:

$$\frac{E90}{E_1}=\left(\frac{1-RCS}{1+RCS}\right)=\frac{1-j\omega RC}{1+j\omega RC}$$

where $S=j\omega$

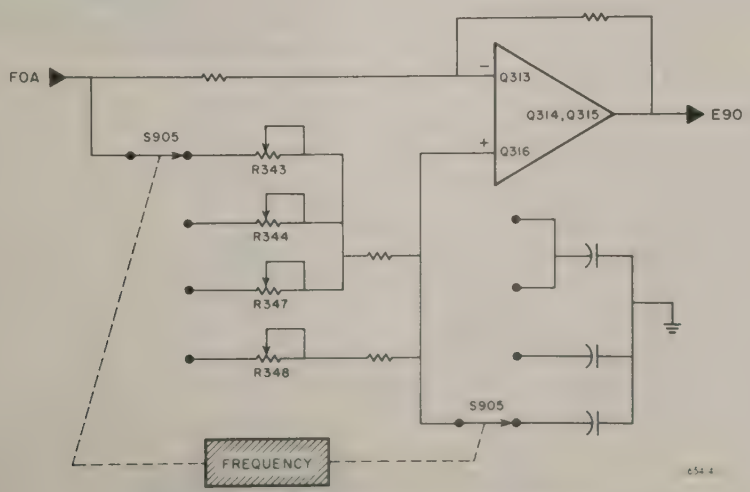

Figure 5-8. Amplifier and 90° phase-shift circuit.

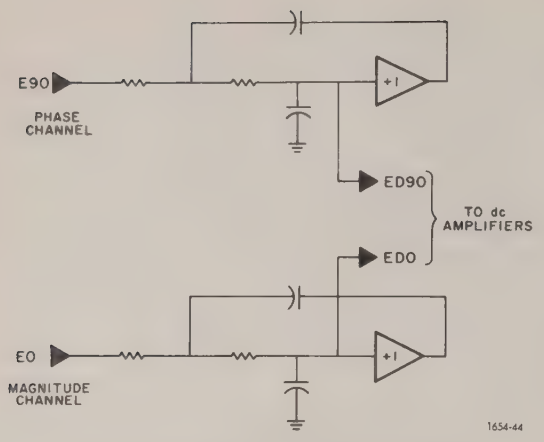

Figure 5-9. Block diagram of detector circuits.

This is the transfer function of an all-pass, phase-shift network whose phase varies from 0° to + 180°. For the values chosen, $\omega RC=1$, the error signal at the output of the amplifier is shifted in phase by 90°. This output is applied to the phase-sensitive detector in the phase-angle difference channel.

Potentiometers R343, R344, R347, and R348 are used for phase adjustment corresponding to the frequency selected by switch, S905.

5.5 DETECTOR CIRCUIT.

5.5.1 General.

The detector circuit board is the second board in the center compartment of the instrument. It contains two phase detectors and two active filters (one for each channel), with additional circuitry required to generate the reference square wave.

The principles of phase detection are described in the following paragraphs for the magnitude (in-phase) channel. The same principles apply equally as well to the phase channel because both channels are identical in design. See Figure 5-9 for a block diagram of the detector circuit.

5.5.2 Phase Detectors.

The phase detector is essentially a switch that opens and closes in coincidence with the oscillation frequency. Exact switching is controlled by a square wave that is referenced to the zero-phase signal of the bridge.

See Figure 5-10. The unbalance signal, EO, is fed to the analog switches Q405 and Q406. Transistor Q405 prevents excessive current from being injected into the signal path. When the drive voltage is sufficiently negative, both Q405 and Q406 are cut off. Two reverse-current components, from the gate-source junction of Q405 and Q406, flow back into the signal source. Only the gate-driven reverse current of Q406 flows into the output signal path.

When the drive voltage is positive, diodes CR404 and CR405 are reverse biased and the gate-source junction of Q405 becomes zero; therefore, Q405 will have a low value of "on" resistance. Transistor Q406 is turned on by Q405. The "on" channel is isolated from the driving circuit by the two diodes, CR404 and CR405. Capacitors C410 and C411 improve the turn-on of Q405. Capacitor C411 is a zero adjustment for 100-kHz operation, it adjusts the leakage currents injected into the signal path from Q405 and Q406 to nearly the same level at 100 kHz as at the other frequencies.

The resultant signal, EDOD, is similar to the waveform shown in Figure 5-11 when the unbalance signal, EO, is magnitude only.

For the phase channel, the circuit is essentially the same, except that the error voltage is first applied through a 90° phase-shift network before it reaches the phase detector. The detected waveform, ED90D, is shown in Figure 5-12.

5.5.3 Active Filters.

The detected output signal, EDOD, is applied to an active low-pass RC filter to obtain sharp cut-off characteristics at low frequency. See Figure 7-8.

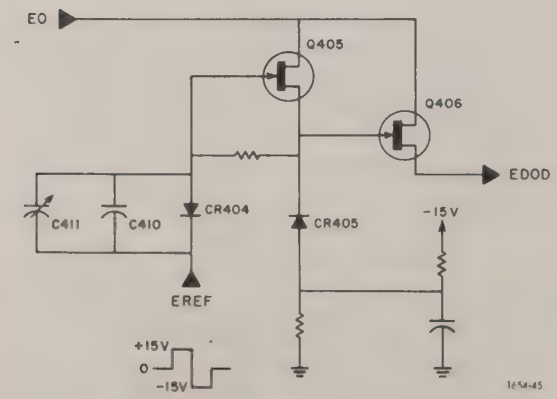

Figure 5-10. Phase-detector circuit.

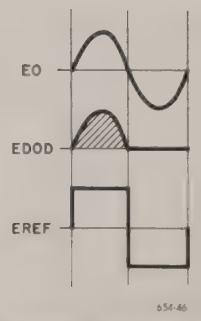

Figure 5-11. Detector waveforms in the MAGNITUDE channel.

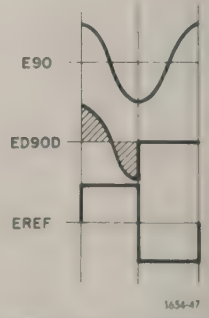

Figure 5-12. Detector waveforms in the PHASE channel.

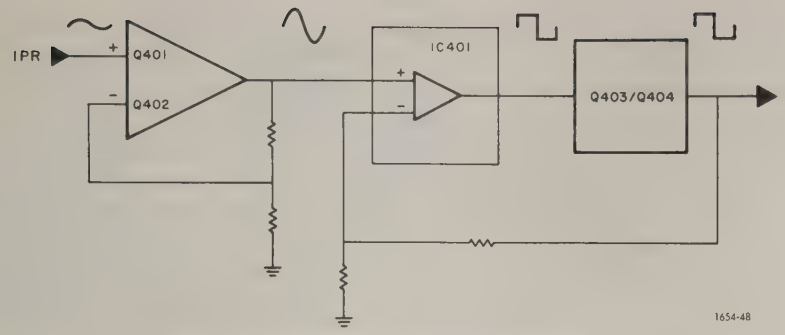

Figure 5-13. Square-wave, reference-signal circuit.

The filter has a second-order Chebyshev response with a cut-off frequency of approximately 10 Hz. Capacitor C424 is switched into the circuit for 100-Hz operation to obtain better filtering, but at a sacrifice of speed of response.

Transistors Q407 and Q408, with high input and low output impedances, provide the ideal unity-gain active elements for the filter.

To eliminate dc drift at the output of the amplifier, the unbalance dc signal, EDO, is taken from the input of Q407 rather than the low-impedance output of the unity-gain amplifier. This drift cannot be distinquished from the error signal when it is fed to the input of the dc amplifier.

5.5.4 Reference Signal.

The square-wave signal that is used to switch the phase detectors is obtained from a reference voltage, IPR, that is taken from one corner of the bridge. The IPR signal is amplified by a high input-impedance amplifier consisting of Q401 and Q402 (see Figure 5-13). The amplified signal is then fed to an integrated-circuit level comparator that has high sensitivity and low hysteresis. The square-wave output of the level comparator is applied to high-level switches Q403 and Q404, and the resultant output is used to drive the phase detectors.

5.6 DC AMPLIFIER BOARD.

5.6.1 General.

The dc-amplifier board is located in the center compartment, the fourth board from the front. The amplifiers for both channels are identical, except for the magnitude linearizer circuit that is added to the magnitude channel to compensate for the usual nonlinearity of the bridge output voltage.

5.6.2 DC Amplifier.

The detected unbalance signal, EDO, is amplified by an operational amplifier that consists of an integrated circuit (IC601) that drives a push-pull output stage, Q601 and

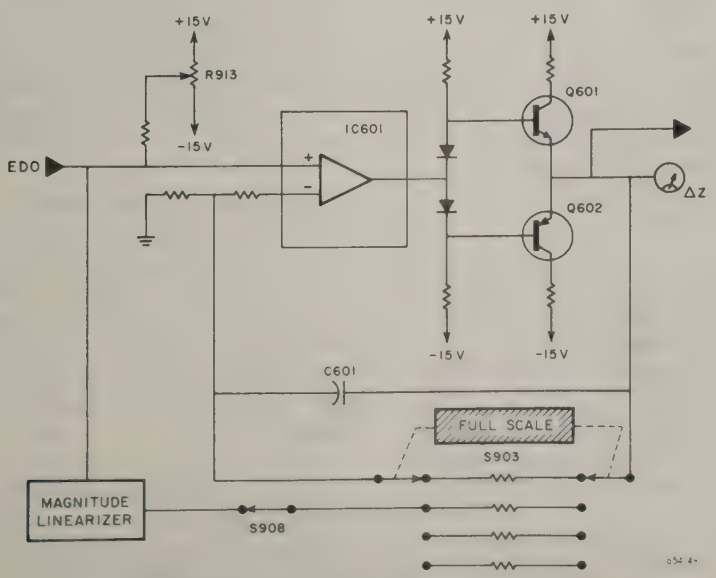

Figure 5-14. DC amplifier with magnitude linearizer.

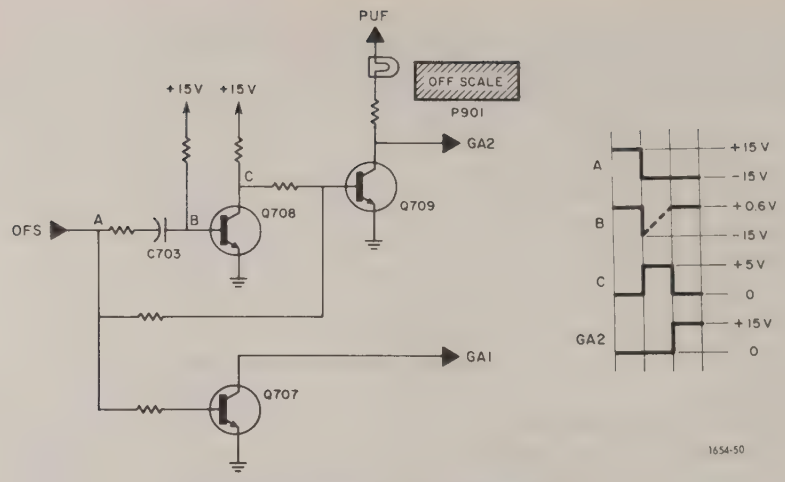

Figure 5-15. OFF SCALE and gate drivers.

Q602 (see Figure 5-14). The output of the amplifier provides the signal for panel-meter indication and the analog output voltage (available at the rear panel) that is proportional to the unbalance signal. The amplifier output also provides strong negative feedback to stabilize gain.

Full-scale switching is achieved by S903. Potentiometer R913 is the ZERO control (on the front panel) that nulls any input offset voltage when the INPUT switch is at the ZERO position. Capacitor C601 is used for high-frequency stability.

5.7 OFF-SCALE AND START.

5.7.1 General.

The OFF SCALE and START circuits are on the last board in the center compartment. The off-scale circuit provides a signal for OFF SCALE indication when the bridge-deviation voltage exceeds the range of the instrument. It also provides two gating signals that disable the external analog-limit comparator during the non-measurement part of the cycle. Self start (when the test component is connected) or external start (by contact closure) is selected via a rear-panel switch.

5.7.2. Overload Amplifiers.

The overload signal, OVS, is amplified by Q701 and its output voltage is rectified by a voltage doubler consisting of C701, CR703, CR704, and C702 (see Figure 7-14).

The peak rectifier, CR704 and C702, draws negligible current from the diode clamper, CR703 and C701. Capacitor C701 charges to the peak voltage, E_s, and the voltage across CR703 is $E_s + e_s$ (e_s = instantaneous voltage). This is peak voltage to the peak rectifier, which charges C702 to the peak voltage, 2 E_s.

The negative dc output of the voltage doubler is then amplified by an operational amplifier that is made up of Q702, Q703, and Q704. Sufficient positive feedback is provided to make the amplifier unstable and drive the output stage of Q704 fully on. The hysteresis is controlled by varying the amount of positive feedback, as determined by R710 and R711.

In normal operation, Q704 is off. Diodes CR701 and CR702 limit the OVS (overload) signal applied to Q701. Diode CR705 limits the negative dc voltage applied to the input of Q702. The output of Q704 is used to control the drivers for the OFF SCALE lamp and gating circuits.

5.7.3 EXT Start.

See Figure 7-14. When the START switch, S907, is set to the EXT position, the measuring time is determined by the time the contacts of J908 remain closed. External contact closure causes Q705 to be cut off, which de-energizes the input relay (K301, Figure 5-7) on the unbalance amplifier board, thus allowing indication of the deviation voltage.

The positive voltage at the collector of Q705 also causes Q706 to be cut off. The negative EXT signal disables the drive circuits for the OFF SCALE condition.

5.7.4 Off-Scale And Gate Drivers.

See Figure 5-15. During overload, the input signal, OFS, is at +15 V and both Q707 and Q709 are turned on. At the same time, the OFF SCALE lamp, P901, is energized. Both GA1 and GA2 are at ground potential and are used to turn off the limit comparator during this measurement interval. GA1 is also used to drive the overload relay (K302, Figure 7-6). The relay switch connects the input of the signal amplifier to ground, thus preventing overdrive of the signal channels.

From overload to measuring condition, the input signal, OFS, changes polarity from +15 V to −15 V. Transistor Q707 is cut off and the gate signal, GA1, is not used. This de-energizes the overload relay, K302, thus allowing the unbalance signal to pass through the signal amplifiers.

Transistor Q709 is also cut off after a delay of 200 ms; the delay is effected by the delay generator, Q708.

The delay generator, generates a positive-going output pulse of a fixed duration from an input pulse of a longer duration, as shown in the waveforms in Figure 5-15. The input pulse, A, is coupled by the capacitor C703 to point B and Q708 is turned off. Then, C703 starts to charge to +15 V. When the charge reaches +0.6 V at point B, Q708 starts to conduct and its output at C drops to about ground potential. This causes Q709 to cut off and both the gate signal, GA2, and the OFF SCALE lamp are turned off.

5.8 POWER SUPPLY.

5.8.1 General.

The power supply is located at the left-rear section of the instrument. The power supply circuit provides two regulated voltages, +15 V and −15 V, and the unregulated ±15 V for the lamp indicators and overload relays.

5.8.2 Operation.

Since the operation of the + supply and − supply are similar, the following analysis will cover the −15 V supply only (see Figure 5-16).

A full-wave rectifier, CR501 and CR502, is utilized to supply an unregulated dc voltage to the emitter of the series regulator, Q505. The collector of Q505 provides the regulated −15 V output to the other circuits in the instrument. This output voltage is also divided by R518, R519, and R520, and it is applied to a set of amplifiers, Q506, Q507, and Q508 that control the conduction of the series regulator in order to maintain a constant −15 V output.

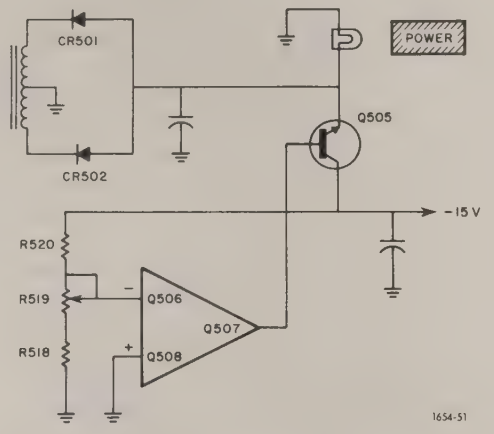

Figure 5-16. Power supply, −15 V.

Service and Maintenance—Section 6

6.1 SERVICE 6-1
6.2 MINIMUM PERFORMANCE STANDARDS 6-1
6.3 CALIBRATION AND CHECKOUT 6-4
6.4 TROUBLE ANALYSIS 6-9
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6.1 SERVICE.

The two-year warranty attests the quality of materials and workmanship in our products. When difficulties do occur, our service engineers will assist in any way possible. If the difficulty cannot be eliminated by use of the following service instructions, please write or phone our Service Department giving full information of the trouble and of steps taken to remedy it. Be sure to mention the type and serial number of the instrument.

Before returning an instrument to General Radio for service, please contact our Service Department or nearest District Office, requesting a "Returned Material Tag." Use of this tag will ensure proper handling and identification. For instruments not covered by the warranty, a purchase order should be forwarded to avoid unnecessary delay.

6.2 MINIMUM PERFORMANCE STANDARDS.

The following procedure is recommended for incoming inspection or periodic operational testing. The equipment required for minimum performance tests and calibration procedure is listed in Table 6-1.

Refer to paragraph 6.3 for a complete calibration procedure, and paragraph 6.4 for trouble analysis should a failure occur.

6.2.1 Preliminary Setup.

Perform the following steps before proceeding with the performance tests:

a. With no power applied, place the 1654 comparator on a flat horizontal surface and check the zero settings on both meters. Adjust mechanical zero, if necessary. The screwdriver adjustment for mechanical zero is located in the center of the lower panel on both meters.

b. Set the power-line input switch on the rear panel to correspond with the power source used and connect the instrument to an appropriate power line.

NOTE

If unfamiliar with the controls and connectors on the 1654 Impedance Comparator, refer to Tables 1-1 and 1-2.

6.2.2 Test Procedure.

FREQUENCIES. Connect a counter between the center conductor of either the UNKNOWN or STANDARD lower connector (8 or 12, Figure 1-2) and the ground jack (10, Figure 1-2). Measure the four test frequencies (100 Hz, 1 kHz, 10 kHz, and 100 kHz) to be within ±1%.

TEST VOLTAGES. Calibrate the instrument (refer to paragraph 3.5). Connect a digital voltmeter as described in the preceding paragraph and measure the approximate values of the three specified test voltages.

ELECTRICAL ZERO. Check electrical zero on both meters by setting the front and rear-panel controls:

FREQUENCY to 1 kHz
INPUT to ZERO
TEST VOLTAGE to 3V
PHASE/FULL SCALE to .001
MAGNITUDE/FULL SCALE to 0.1
START (rear panel) to SELF

a. Adjust the ZERO screwdriver adjustments to zero both meters. (These adjustments are located on the front panel close to the lower panels of both meters.)

TABLE 6-1
TEST EQUIPMENT

Type	*Requirements*	*Model Recommended*
Digital voltmeter	Range: ac, 0-3 V dc, ±0-15 V Accuracy: ac, ±0.5% of reading dc, ±0.1% of full scale	GR 1820 Digital Voltmeter with 1820-P1 or -P2 plug-in.
Frequency counter	Range: 100 Hz - 100 kHz Accuracy: ±1%	GR 1191 Counter
Decade Resistor	Range: 700 Ω - 1300 Ω in 10 Ω steps Accuracy: ±0.05%	GR 1434-N Decade Resistor
Test Resistors	100 Ω (0.1%), film (2) 1 kΩ (1%), film 1 kΩ (0.01%), wire-wound	
Test Capacitors	0.001 μF (0.05%)	GR 1409-F (P/N 1409-9706)
	0.01 μF (0.05%)	GR 1409-L (P/N 1409-9712)
	0.1 μF (0.05%)	GR 1409-T (P/N 1409-9720)
	1.0 μF (0.05%)	GR 1409-Y (P/N 1409-9725)
Adaptors (2)	GR874 to binding post	GR874-MB Coupling Probe

b. Set the FREQUENCY control to 10 kHz and check that both meters indicate zero within ±¾ of a division on the top scale.

c. Repeat the procedure described in step b, with the FREQUENCY control set at 100 Hz and 100 kHz.

(11) MAGNITUDE/FULL SCALE CAL. Set the front and rear-panel controls:

MEASUREMENT to RESISTANCE/INDUCTANCE
FREQUENCY to 1 kHz
TEST VOLTAGE to 1 V
MAGNITUDE/FULL SCALE to 1
INPUT to CAL 1%
START (rear panel) to SELF
LINEARIZER (rear panel) to IN

a. Connect a digital voltmeter to the ANALOG VOLTAGE OUTPUT connector (S0910, pin B) at the rear panel.

b. Adjust the CALIBRATE control on the front panel for a +10.00 –V reading on the DVM. The MAGNITUDE DIFFERENCE meter should indicate +10.0.

(12) PHASE ANGLE/FULL SCALE CAL. Set the front-panel controls:

TEST VOLTAGE to 1 V
PHASE ANGLE/FULL SCALE to 0.1
INPUT to GUARDED
MEASUREMENT to RESISTANCE/INDUCTANCE

a. Connect a 100-Ω (0.1%) film resistor across the STANDARD terminals.

b. Connect a 100-Ω (0.1%) film resistor in parallel with a 0.1 μF (0.05)% capacitor across the UNKNOWN terminals.

c. Connect a digital voltmeter to the ANALOG VOLTAGE OUTPUT connector (S0910, pin A) at the rear panel.

d. Adjust the CALIBRATE control on the front panel

TABLE 6-2
MAGNITUDE CAL. WITH LARGE θ

Frequency	*Capacitor (UNK Terminals)*	*Approximate θ Meter Indication*	*Z Meter Indication*
100 Hz	1.0 μF ±0.05%	0.063	−0.197 + (error)%
10 kHz	0.01 μF ±0.05%	0.061	−0.197 + (error)%
100 kHz	0.001 μF ±0.05%	0.060	−0.197 + (error)%

for a −6.00-V reading on the DVM. The PHASE ANGLE DIFFERENCE meter should indicate −6.0.

e. Set the MEASUREMENT control to CAPACITANCE. The PHASE ANGLE DIFFERENCE meter should indicate +6.0 ±0.3.

f. Set the MEASUREMENT control to RESISTANCE/INDUCTANCE.

(67) MAGNITUDE CAL. WITH LARGE θ. Connect 100-Ω (0.1%) film resistors across the STANDARD terminals and across the UNKNOWN terminals. Set the front and rear-panel controls:

MEASUREMENT to RESISTANCE/INDUCTANCE
FREQUENCY to 1 kHz
TEST VOLTAGE to 1 V
INPUT to CAL 1%
LINEARIZER (rear panel) to IN
PHASE ANGLE/FULL SCALE to 0.1
MAGNITUDE/FULL SCALE to 1

a. Calibrate the magnitude for 1% full scale (refer to paragraph 3.5).

b. Set the INPUT control to GUARDED and the MAGNITUDE/FULL SCALE control to 0.3.

TABLE 6-3
MAGNITUDE LINEARIZER CHECK.

Test Voltage Setting	*Magnitude/F.S. Setting*	*Decade Resistor Setting*	*Magnitude Difference Meter Reading*
0.3 V	10	1100 Ω	+ (9.7 – 10.3)
0.3 V	30	1300 Ω	+ (2.91 – 3.09)
0.3 V	30	700 Ω	– (2.91 – 3.09)
0.3 V	10	900 Ω	– (9.7 – 10.3)
Set TEST VOLTAGE control to 1 V and recalibrate (step a).			
1 V	10	900 Ω	– (9.7 – 10.3)
1 V	10	1100 Ω	+ (9.7 – 10.3)
1 V	3	1200 Ω	≈ +3 div. (OFF SCALE lamp on)

c. Note the magnitude error (difference between the two 100-Ω resistors) indicated on the DVM.

d. Connect a 0.1 μF (0.05%) capacitor, in parallel with the resistor, across the unknown terminals.

e. The MAGNITUDE DIFFERENCE METER should indicate −0.19% + error noted in step d. The PHASE ANGLE DIFFERENCE meter should indicate ≈ −0.063.

f. The MAGNITUDE DIFFERENCE METER should indicate −0.197% + error noted in step d. The PHASE ANGLE DIFFERENCE meter should indicate ≈ −0.063.

Repeat the above procedure, using the FREQUENCY control settings and capacitors listed in Table 6-2. Be sure to repeat step a above, with each change in frequency.

PHASE ANGLE CAL. WITH LARGE Z. Set the front-panel controls:

FREQUENCY to 1 kHz
MEASUREMENT to RESISTANCE/INDUCTANCE
TEST VOLTAGE to 1V
MAGNITUDE/FULL SCALE to 1
PHASE ANGLE/FULL SCALE TO .003
INPUT to CAL 1%

a. Calibrate for 1% full scale (refer to paragraph 3.5).

b. Connect a 100-Ω (0.1%) film resistor across the STANDARD terminals.

c. Connect a 100-Ω (0.1%) film resistor, in parallel with a 1-kΩ (1%) film resistor across the UNKNOWN terminals.

d. Set the MAGNITUDE/FULL SCALE control to 10% and the INPUT control to GUARDED.

e. The change in the PHASE ANGLE DIFFERENCE meter reading should be less than 1.5 divisions (on top scale) as the MEASUREMENT control is switched alternately to both positions. The MAGNITUDE meter reading should be ≈ 9.1%.

Repeat the above procedure, using the 100 Hz, 10 kHz, and 100 kHz FREQUENCY control settings. Be sure to repeat step a, with each change in frequency.

LINEARIZER. Set the front-panel controls:

FREQUENCY to 1 kHz
MEASUREMENT to RESISTANCE/INDUCTANCE
INPUT to CAL 1%
TEST VOLTAGE to 0.3
MAGNITUDE/FULL SCALE to 1

a. Calibrate for 1% full scale (refer to paragraph 3.5).

b. Set the INPUT control to GUARDED.

c. Connect a 1-kΩ (0.01%) resistor to the STANDARD terminals.

d. Connect a decade resistor to the UNKNOWN terminals.

e. Make the measurements indicated in Table 6-3, and observe the measurement limits on the MAGNITUDE DIFFERENCE meter.

6.3 CALIBRATION AND CHECKOUT.

To calibrate the 1654, using external controls only, refer to paragraph 3.5. This is the normal operating calibration that is recommended when the test frequency is changed and when impedance measurement are to be made at the extremes of the normal measurement ranges.

The procedure for complete calibration of the instrument after major repairs or adjustments have been made, is given in the following paragraphs.

6.3.1 Equipment Required.

The calibration procedure is similar to the minimum performance tests (refer to paragraph 6.2) and the equipment required for both procedures is listed in Table 6-1. The equipment specifications given in Table 6-1 are minimum requirements and equivalent models may be substituted for the equipment recommended.

6.3.2 Calibration Procedure.

Remove the instrument cabinet (refer to paragraph 2.3.2) and proceed with the following calibration and checkout procedure.

MECHANICAL ZERO. With no power applied and with the instrument in its normal horizontal operating position, adjust mechanical zero on both meters. The screwdriver adjustment for mechanical zero is located in the center of the lower panel on both meters.

±15-V SUPPLY. Connect the instrument to power line (all plug-in etched boards must be installed) and measure the voltage at AT505/506 (see Figure 2-8) on the power-supply etched board. If necessary, adjust R519 (see Figure 6-1) to obtain a voltage reading of −15.0 V.

Measure the voltage at AT501/502 (see Figure 2-8). The voltage reading should be +15±0.4 V. If necessary, readjust R501 to split the error as evenly as possible between the +15- and −15-V supplies.

OSCILLATOR FREQUENCIES. Connect the counter between terminal #11 on transformer T901 and the instrument chassis. Table 6-4 lists the adjustments and frequency limits for the four oscillator frequencies. Measure the frequency with the counter and make the necessary adjustments as indicated in the table.

Table 6-4

OPERATING-FREQUENCY ADJUSTMENTS

Operating Frequency	Adjustment (See Figure 6-2)	Frequency Limit
100 Hz	R111	±1%
1 kHz	R112	±1%
10 kHz	R113	±1%
100 kHz	R114	±1%

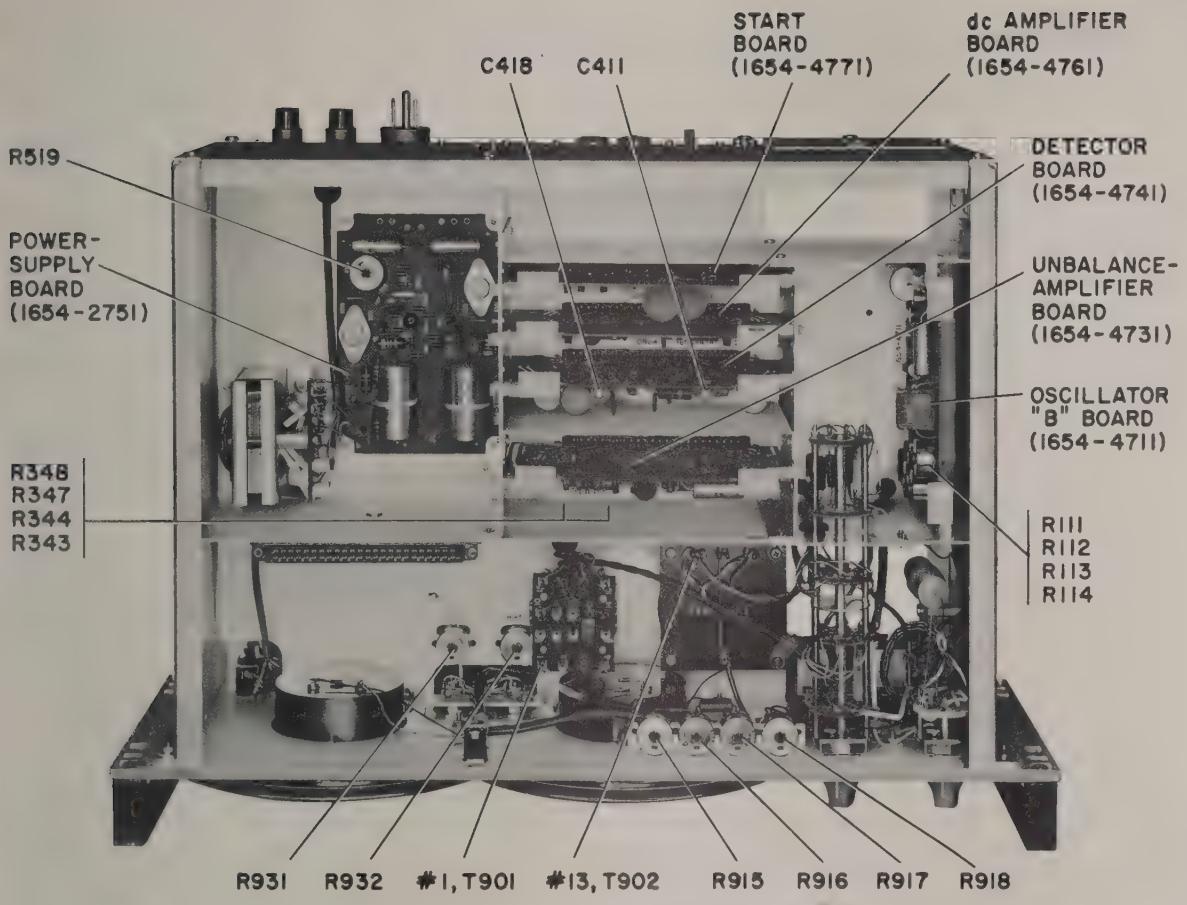

Figure 6-1. Top interior of 1654 Impedance Comparator.

TEST VOLTAGE. Using the digital voltmeter, measure the ac voltage at terminal #13 on transformer T902 (see Figure 6-1). This measurement should be made for each test voltage, as indicated in Table 6-5.

Before making each measurement listed in the table, the instrument should be calibrated (CAL 1%) as follows:

a. Set the MAGNITUDE/FULL SCALE control to 1 and the INPUT control to CAL 1%.

Table 6-5

TEST VOLTAGES

Test Voltage Control Setting	*Approximate DVM Reading (T902, #13)*
0.3 V	0.30 V rms
1 V	0.95 V rms
3 V	3.00 V rms

b. Adjust the CALIBRATE control to obtain a 1% (full-scale) reading on the MAGNITUDE DIFFERENCE meter. (Ignore the PHASE ANGLE DIFFERENCE meter reading).

ELECTRICAL ZERO. To set electrical zero on the front panel meters.

Set the front-panel controls.

FREQUENCY to 1 kHz
INPUT to ZERO
TEST VOLTAGE to 3 V
PHASE/FULL SCALE to .001
MAGNITUDE/FULL SCALE to 0.1

a. Adjust the ZERO screwdriver adjustment (R913) on the front panel to zero the MAGNITUDE DIFFERENCE meter.

b. Repeat the adjustment (step b) using the ZERO adjustment (R914) to zero the PHASE ANGLE DIFFERENCE meter.

c. Set the FREQUENCY control on the front panel to 100 kHz. Adjust C411 and C418 on the detector-circuit etched board (see Figure 6-1) to zero both meters.

NOTE

The added capacitance of the adjustment tool used in step d will have an effect on the adjustment. The adjustment may have to be repeated, with the tool removed between each adjustment.

d. Set the FREQUENCY control to 10 kHz. Check the zero setting on both meters, the pointer should be within 1/2 division of zero on the top scale.

e. Set the FREQUENCY control to 100 Hz and repeat step d.

(9) MAGNITUDE/FULL SCALE CAL. Set front and rear-panel controls.

TEST VOLTAGE to 0.3 V
MAGNITUDE/FULL SCALE to 1
INPUT to CAL 1%
MEASUREMENT to RESISTANCE/INDUCTANCE
FREQUENCY to 1 kHz
START (rear panel) to SELF
MAGNITUDE LINEARIZER (rear panel) to IN

a. Using a digital voltmeter, measure the magnitude ANALOG VOLTAGE OUTPUT (SO910, pin B) at the rear panel. Adjust the CALIBRATE control on the front panel for a +10.0 V output.

b. Adjust R932 (see Figure 6-1) for a reading of +10.0 on the MAGNITUDE DIFFERENCE meter.

c. Check the ANALOG LIMIT COMPARATOR output (SO909, pin B) at the rear panel. The output should be +10.0 V.

(10) MAGNITUDE-DIFFERENCE RANGES. Set front and rear-panel controls.

FREQUENCY to 1 kHz
MEASUREMENT to RESISTANCE/INDUCTANCE
TEST VOLTAGE to 0.3 V
MAGNITUDE/FULL SCALE to 1
INPUT to CAL 1%
MAGNITUDE LINEARIZER (rear panel) to IN

a. Adjust the CALIBRATE control to obtain a 1% (full-scale reading on the MAGNITUDE DIFFERENCE meter.

b. Set the INPUT control to GUARDED.

c. Connect a 1-kΩ (0.01%) wire-wound resistor across the STANDARD terminals. Use GR 874-MB Coupling Probes to adapt the comparator terminals for this connection.

d. Connect the 700-Ω to 1300-Ω decade resistor (1434-N) across the UNKNOWN terminals, using GR 874-MB Coupling Probes. Set the decade resistor to 1000 Ω.

e. Adjust the ZERO screwdriver adjustment to zero the MAGNITUDE DIFFERENCE meter.

f. Perform the measurements indicated in Table 6-6.

g. Set the decade resistor to 9X0 Ω.

h. Repeat the adjustment described in step e.

i. Perform the measurements indicated in Table 6-7.

j. Set the INPUT control to ZERO.

k. Repeat step e.

l. Set the front-panel controls:

TEST VOLTAGE to 1 V
MAGNITUDE/FULL SCALE to 1
INPUT to CAL 1%

Table 6-6

MAGNITUDE-DIFFERENCE RANGE CHECKS

MAGNITUDE /FULL SCALE Setting	*Decade Resistor Setting (Ω)*	*MAGNITUDE DIFFERENCE Meter Indication*
1	1010	+ (1.0 ±0.03)%
3	1010	+ (1.0 ± 0.09)%
10	1100	+ (10 ±0.3)%*
30	1100	+ (10 ±0.9)%*
30	1200	+ (20 ±0.9)%*
30	1300	+ (30 ±0.9)%*

*+ Linearizer check.

Table 6-7

MAGNITUDE-DIFFERENCE RANGE CHECKS

MAGNITUDE /FULL SCALE Setting	*Decade Resistor Setting (Ω)*	*MAGNITUDE DIFFERENCE Meter Indication*
1	990	– (1.0 ±0.03)%
3	990	– (1.0 ±0.09)%
10	900	– (10 ±0.3)%*
30	900	– (10 ±0.9)%*
30	800	– (20 ±0.9)%*
30	700	– (30 ±0.9)%*

* – Linearizer check.

m. Adjust the CALIBRATE control to obtain a 1% (full-scale) reading on the MAGNITUDE DIFFERENCE meter.

n. Set the INPUT control to GUARDED.

o. Perform the LINEARIZER measurements indicated in Table 6-8.

Table 6-8

MAGNITUDE-DIFFERENCE RANGE CHECKS

MAGNITUDE/FULL SCALE Setting	*Decade Resistor Setting (Ω)*	*MAGNITUDE DIFFERENCE Meter Indication*
10	900	– (10 ±0.3)%
10	1100	+ (10 ±0.3)%

p. Set the INPUT control to UNGUARDED (the MAGNITUDE DIFFERENCE meter reading should not change).

q. With the MAGNITUDE/FULL SCALE control set at 0.3 and the decade resistor set at 1200 Ω, the OFF SCALE lamp should 9/0 W and the MAGNITUDE DIFFERENCE meter should indicate ≈ +3 divisions.

PHASE-ANGLE/FULL-SCALE CAL. Set the front-panel control.

FREQUENCY to 1 kHz
TEST VOLTAGE to 1 V
MAGNITUDE/FULL SCALE to 10
PHASE ANGLE/FULL-SCALE to 0.1
INPUT to GUARDED
MEASUREMENT to RESISTANCE/INDUCTANCE

a. Connect a 100-Ω (0.1%) film resistor across the STANDARD terminals.

b. Connect a 100-Ω (0.1%) film resistor in parallel with a 0.1 μF (0.05%) capacitor across the UNKNOWN terminals.

c. Using the digital voltmeter, measure the phase ANALOG VOLTAGE OUTPUT (SO910, pin A) at the rear panel. Adjust the CALIBRATE control on the front panel for a –6.00-V reading on the DVM.

d. Adjust R931 (see Figure 6-1) for a reading of –0.06 radian on the PHASE ANGLE DIFFERENCE meter.

e. Using the DVM, observe the ANALOG LIMIT COMPARATOR output (SO909, pin A) at the rear panel. The output should be –6.00 V.

f. Set the MEASUREMENT control to CAPACITANCE. The PHASE ANGLE DIFFERENCE meter should indicate a +(0.060 ±0.003) radian reading.

PHASE-ANGLE DIFFERENCE RANGES. Set the front-panel controls.

FREQUENCY to 1 kHz
TEST VOLTAGE to 1 V
MAGNITUDE/FULL SCALE to 10
PHASE ANGLE/FULL SCALE to 0.1
INPUT to GUARDED.
MEASUREMENT to RESISTANCE/INDUCTANCE

a. Repeat step c in the previous check, PHASE-ANGLE/FULL-SCALE CAL.

b. Connect a 100-Ω (0.1%) film resistor across the STANDARD terminals.

c. Connect a 100-Ω (0.1%) film resistor in parallel with a capacitor across the UNKNOWN terminals. Refer to Table 6-9 for the capacitor values required.

d. Perform the measurements indicated in Table 6-9.

Table 6-9

PHASE-ANGLE-DIFFERENCE RANGE CHECKS

1654 Control Settings θ *FULL SCALE*	*MEASUREMENT*	*C Used at UNKNOWN*	*PHASE ANGLE Meter Indication*
.03	CAPACITANCE	0.01 μF	+ (0.006 ±0.0009)
.03	RESISTANCE/INDUCTANCE	0.01 μF	– (0.006 ±0.0009)
.01	RESISTANCE/INDUCTANCE	0.01 μF	– (0.006 ±0.0003)
.01	CAPACITANCE	0.01 μF	+ (0.006 ±0.0003)
.003	CAPACITANCE	0.001 μF	+ (0.0006 ±0.00009)
.003	RESISTANCE/INDUCTANCE	0.001 μF	– (0.0006 ±0.00009)

Table 6-10

Z CAL WITH LARGE PHASE ERROR

Frequency	*C used at UNKNOWN*	*Potentiometer Adjustment (see Figure 6-1)*	*Approximate θ Meter Indication*
100 Hz	1.0 μF ±0.05%	R915	0.063 rad.
10 kHz	0.01 μF ±0.05%	R917	0.061 rad.
100 kHz	0.001 μF ±0.05%	R918	0.060 rad.

Z CAL WITH LARGE PHASE ERROR. Connect a 100-Ω (0.1%) film resistors (one each) across the STANDARD terminals and across the UNKNOWN terminals. Set the front and rear-panel controls.

MEASUREMENT to RESISTANCE/INDUCTANCE
FREQUENCY to 1 kHz
TEST VOLTAGE to 1 V
INPUT to CAL 1%
PHASE/FULL SCALE to 0.1
MAGNITUDE/FULL SCALE to 1
MAGNITUDE LINEARIZER (rear panel) to IN

a. Connect the digital voltmeter to the ANALOG VOLTAGE OUTPUT (SO910, pin B) at the rear panel.

b. Calibrate the magnitude for 1% full scale (refer to CAL 1% procedure under TEST VOLTAGE). This calibration should produce a +10.00-V reading on the digital voltmeter.

c. Set INPUT control to GUARDED and MAGNITUDE/FULL SCALE control to 0.3.

d. Note the magnitude error (difference between the two 100-Ω resistors) indicated on the digital voltmeter.

e. Connect a 0.1 μF (0.05%) capacitor, in parallel with the resistor, across the UNKNOWN terminals.

f. Adjust R916 (see Figure 6-1) for a MAGNITUDE DIFFERENCE meter reading of –0.197 ± (error noted in step d). The PHASE ANGLE DIFFERENCE meter should indicate ≈ –0.063 radian.

g. Set MEASUREMENT control to CAPACITANCE. Both meters should indicate the same values as noted in step f, but + (positive).

h. Repeat the above procedure, using the FREQUENCY control settings and capacitors listed in Table 6-10. Be sure to calibrate (CAL 1%) before making each potentiometer adjustments.

CAL WITH LARGE MAGNITUDE ERROR. Set the front-panel controls.

FREQUENCY to 1 kHz
MEASUREMENT to RESISTANCE/INDUCTANCE
TEST VOLTAGE to 1 V
MAGNITUDE/FULL SCALE to 1
PHASE ANGLE/FULL SCALE to .003
INPUT to CAL 1%

a. Calibrate for 1% full scale (refer to CAL 1% procedure under TEST VOLTAGE).

b. Connect a 100-Ω (0.1%) film resistor across the STANDARD terminals. Connect a 100-Ω (0.1%) film resistor in parallel with a 1-kΩ (1%) film resistor across the UNKNOWN terminals.

c. Set MAGNITUDE/FULL SCALE control to 10 and INPUT control to GUARDED.

d. Adjust R344 (see Figure 6-1) for no change in the PHASE ANGLE DIFFERENCE meter reading as the MEASUREMENT control is switched alternately to both positions.

e. Repeat the above procedure using the FREQUENCY control settings listed in Table 6-11. Be sure to calibrate (CAL 1%) before making each potentiometer adjustment.

OFF-SCALE LAMP and CONTROL-SIGNAL OUTPUT. Set front-panel controls.

Table 6-11

θ CAL WITH LARGE MAGNITUDE ERROR

Frequency	*Potentiometer Adjustment (see Figure 6-1)*	*Approximate θ Meter Indication*
100 Hz	R343	0
10 kHz	R347	0
100 kHz	R348	≈ –3 div

MEASUREMENT to RESISTANCE/INDUCTANCE
INPUT to GUARDED
FREQUENCY to 1 kHz
TEST VOLTAGE to 1 V
MAGNITUDE/FULL SCALE to 10

a. Connect a 100-Ω (0.1%) film resistor across the STANDARD terminals. Connect a 100-Ω (0.1%) film resistor in parallel with a 1-kΩ (1%) film resistor across the UNKNOWN terminals.

b. The MAGNITUDE DIFFERENCE meter should indicate ≈ –9.1.

c. Set the START control (rear panel) to EXT. The OFF SCALE lamp should light and the MAGNITUDE DIFFERENCE meter should indicate ≈ 0.

d. Note the action of the OFF SCALE lamp with each setting of the INPUT control:

UNGUARDED - lamp on
ZERO - lamp off
CAL 1% - lamp off

Return the INPUT control to the GUARDED position.

e. Ground the START jack (rear panel). The OFF SCALE lamp should go out and the meter should again indicate the reading noted in step b.

f. Remove the ground from the START jack and set the START switch to SELF.

g. Ground GA1 output (ANALOG LIMIT COMPARATOR socket, rear panel, pin D). The MAGNITUDE DIFFERENCE meter should indicate a ≈ 0 reading and the OFF SCALE lamp should be off.

h. Ground GA2 output (ANALOG LIMIT COMPARATOR socket, rear panel, pin C). The OFF SCALE lamp should light.

Remove all ground connections described in the above procedure.

6.4 TROUBLE ANALYSIS.

The calibration and checkout procedure in paragraph 6.3 will either correct or localize most minor problems. If a problem still exists, the following procedure should locate the difficulty:

NOTE

The schematic diagrams in Section 7 contain the test voltages and waveforms necessary to trouble-shoot the circuits.

a. Set the INPUT control to ZERO. If the meter zeros are off scale, check out the oscillator output and power supplies (see Figures 7-4 and 7-10).

b. If ZERO positions are satisfactory, set INPUT to CAL 1%. If no CAL signal indicated, trace CAL signal through unbalance amplifier (Figure 7-6), detectors (Figure 7-8) and dc amplifiers (Figure 7-12).

c. If CAL indication satisfactory, trace unbalance signal, BOU, through unbalance amplifier (Figure 7-6).

d. If the OFF SCALE lamp fails to light for a large magnitude difference, check relay K301 and control signal EXR & OVS (Figure 7-6).

e. If the OFF SCALE lamp is on but there is no meter indication, check to see if the START switch (rear panel) is set at SELF.

6.5 KNOB REMOVAL.

If it should be necessary to remove the knob on a front-panel control, either to replace one that has been damaged or to replace the associated control, proceed as follows:

a. Grasp the knob firmly with the fingers and pull the knob straight away from the panel.

b. Observe the position of the setscrew in the bushing, with respect to any panel marking (or at the full ccw position of a continuous control).

c. Release the setscrew and pull the bushing off the shaft.

NOTE

To separate the bushing from the knob, if for any reason they should be combined off the instrument, drive a machine tap a turn or two into the bushing for a sufficient grip for easy separation.

6.6 KNOB INSTALLATION.

To install a knob assembly on the control shaft:

a. Mount the bushing on the shaft, using a small slotted piece of wrapping paper as a shim, for adequate panel clearance.

b. Orient the setscrew on the bushing with respect to the panel-marking index and lock the setscrews.

NOTE

Make sure that the end of the shaft does not protrude through the bushing or the knob won't seat properly.

c. Place the knob on the bushing with the retention spring opposite the setscrew.

d. Push the knob in until it bottoms and pull it slightly to check that the retention spring is seated in the groove in the bushing.

NOTE

If the retention spring in the knob comes loose, reinstall it in the interior notch with the small slit, in the outer wall.

Parts Lists and Diagrams–Section 7

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Federal Manufacturers Code	7-2
Mechanical Replacement Parts, Front-Panel	7-3
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Schematic	Etched-Board Assembly P/N	Reference No. Series
Oscillator and Bridge	1654-4711	100, 900
Unbalance Amplifier	1654-4731	300
Detector Circuit	1654-4741	400
Power Supply	1654-2751	500
DC Amplifier	1654-4761	600
Start Circuit	1654-4771	700

FEDERAL MANUFACTURER'S CODE

From Federal Supply Code for Manufacturers Cataloging Handbooks H4-1 (Name to Code) and H4-2 (Code to Name) as supplemented through August, 1968.

Code	Manufacturer
00192	Jones Mfg. Co, Chicago, Illinois
00194	Waisco Electronics Corp, L.A., Calif.
00434	Schweber Electronics, Westburg, L.I., N.Y.
00656	Aerovox Corp, New Bedford, Mass.
01009	Alden Products Co, Brockton, Mass.
01121	Allen-Bradley, Co, Milwaukee, Wisc.
01295	Texas Instruments, Inc, Dallas, Texas
02114	Ferroxcube Corp, Saugerties, N.Y. 12477
02606	Fenwal Lab Inc, Morton Grove, Ill.
02660	Amphenol Electron Corp, Broadview, Ill.
02768	Fastex, Des Plaines, Ill. 60016
03503	G.E. Semicon Prod, Syracuse, N.Y. 13201
03636	Grayburne, Yonkers, N.Y. 10701
03888	Pyrofilm Resistor Co, Cedar Knolls, N.J.
03911	Clairex Corp, New York, N.Y. 10001
04009	Arrow-Hart & Hegeman, Hartford, Conn. 06106
04713	Motorola, Phoenix, Ariz. 85008
05170	Engr'd Electronics, Santa Ana, Calif. 92702
05624	Barber-Colman Co, Rockford, Ill. 61101
05820	Wakefield Eng, Inc, Wakefield, Mass. 01880
07126	Digitron Co, Pasadena, Calif.
07127	Eagle Signal (E.W. Bliss Co), Baraboo, Wisc.
07261	Avnet Corp, Culver City, Calif. 90230
07263	Fairchild Camera, Mountain View, Calif.
07387	Birtcher Corp, No. Los Angeles, Calif.
07595	Amer Semicond, Arlington Hts, Ill. 60004
07828	Bodine Corp, Bridgeport, Conn. 06605
07829	Bodine Electric Co, Chicago, Ill. 60618
07910	Cont Device Corp, Hawthorne, Calif.
07983	State Labs Inc, N.Y., N.Y. 10003
07999	Borg Inst., Delavan, Wisc. 53115
08730	Vemaline Prod Co, Franklin Lakes, N.J.
09213	G.E. Semiconductor, Buffalo, N.Y.
09408	Star-Tronics Inc, Georgetown, Mass. 01830
09823	Burgess Battery Co, Freeport, Ill.
09922	Burndy Corp, Norwalk, Conn. 06852
11236	C.T.S. of Berne, Inc, Berne, Ind. 46711
11599	Chandler Evans Corp, W. Hartford, Conn.
12040	National Semiconductor, Danbury, Conn.
12498	Crystalonics, Cambridge, Mass. 02140
12672	RCA, Woodbridge, N.J.
12697	Clarostat Mfg Co, Inc, Dover, N.H. 03820
12954	Dickson Electronics, Scottsdale, Ariz.
13327	Solitron Devices, Tappan, N.Y. 10983
14433	ITT Semicondictors, W.Palm Beach, Fla.
14655	Cornell-Dubilier Electric Co, Newark, N.J.
14674	Corning Glass Works, Corning, N.Y.
14936	General Instrument Corp, Hicksville, N.Y.
15238	ITT, Semiconductor Div, Lawrence, Mass.
15605	Cutler-Hammer Inc, Milwaukee, Wisc. 53233
16037	Spruce Pine Mica Co, Spruce Pine, N.C.
17771	Singer Co, Diehl Div, Somerville, N.J.
19396	Illinois Tool Works, Pekton Div, Chicago, Ill.
19644	LRC Electronics, Horseheads, N.Y.
19701	Electra Mfg Co, Independence, Kansas 67301
21335	Fafnir Bearing Co, New Briton, Conn.
22753	UID Electronics Corp, Hollywood, Fla.
23342	Avnet Electronics Corp, Franklin Park, Ill.
24446	G.E., Schenectady, N.Y. 12305
24454	G.E., Electronics Comp, Syracuse, N.Y.
24455	G.E. (Lamp Div), Nela Park, Cleveland, Ohio
24655	General Radio Co, W. Concord, Mass. 01781
26806	American Zettler Inc, Costa Mesa, Calif.
28520	Heyman Mfg Co, Kenilworth, N.J.
28959	Hoffman Electronics Corp, El Monte, Calif.
30874	I.B.M, Armonk, New York
32001	Jensen Mfg. Co, Chicago, Ill. 60638
33173	G.E. Comp, Owensboro, Ky. 42301
35929	Constanta Co, Mont. 19, Que.
37942	P.R. Mallory & Co Inc, Indianapolis, Ind.
38443	Marlin-Rockwell Corp, Jamestown, N.Y.
40931	Honeywell Inc, Minneapolis, Minn. 55408
42190	Muter Co, Chicago, Ill. 60638
42498	National Co, Inc, Melrose, Mass. 02176
43991	Norma-Hoffman, Stanford, Conn. 06904
49671	RCA, New York, N.Y. 10020
49956	Raytheon Mfg Co, Waltham, Mass. 02154
53021	Sangamo Electric Co, Springfield, Ill. 62705
54294	Shallcross Mfg Co, Selma, N.C.
54715	Shure Brothers, Inc, Evanston, Ill.
56289	Sprague Electric Co, N. Adams, Mass.
59730	Thomas and Betts Co, Elizabeth, N.J. 07207
59875	TRW Inc, (Accessories Div), Cleveland, Ohio
60399	Torrington Mfg Co, Torrington, Conn.
61637	Union Carbide Corp, New York, N.Y. 10017
61864	United-Carr Fastener Corp, Boston, Mass.
63060	Victoreen Instrument Co, Inc, Cleveland, O.
63743	Ward Leonard Electric Co, Mt. Vernon, N.Y.
65083	Westinghouse (Lamp Div), Bloomfield, N.J.
65092	Weston Instruments, Newark, N.J.
70485	Atlantic-India Rubber, Chicago, Ill. 60607
70563	Amperite Co, Union City, N.J. 07087
70903	Belden Mfg Co, Chicago, Ill. 60644
71126	Bronson, Homer D, Co, Beacon Falls, Conn.
71294	Canfield, H.O. Co, Clifton Forge, Va. 24422
71400	Bussman (McGraw Edison), St. Louis, Mo.
71468	ITT Cannon Elec, L.A., Calif. 90031
71590	Centralab, Inc, Milwaukee, Wisc, 53212
71666	Continental Carbon Co, Inc, New York, N.Y.
71707	Coto Coil Co Inc, Providence, R.I.
71744	Chicago Miniature Lamp Works, Chicago, Ill.
71785	Cinch Mfg Co, Chicago, Ill. 60624
71823	Darnell Corp, Ltd, Downey, Calif. 90241
72136	Electro Motive Mfg Co, Wilmington, Conn.
72259	Nytronics Inc, Berkeley Heights, N.J. 07922
72619	Dialight Co, Brooklyn, N.Y. 11237
72699	General Instr Corp, Newark, N.J. 07104
72765	Drake Mfg Co, Chicago, Ill. 60656
72825	Hugh H. Eby Inc, Philadelphia, Penn. 19144
72962	Elastic Stop Nut Corp, Union, N.J. 07083
72982	Erie Technological Products Inc, Erie, Penn.
73138	Beckman Inc, Fullerton, Calif. 92634
73445	Amperex Electronics Co, Hicksville, N.Y.
73559	Carling Electric Co, W.Hartford, Conn.
73690	Elco Resistor Co, New York, N.Y.
73899	JFD Electronics Corp, Brooklyn, N.Y.
74193	Heinemann Electric Co, Trenton, N.J.
74861	Industrial Condenser Corp, Chicago, Ill.
74970	E.F. Johnson Co, Waseca, Minn. 56093
75042	IRC Inc, Philadelphia, Penn. 19108
75382	Kulka Electric Corp, Mt. Vernon, N.Y.
75491	Lafayette Industrial Electronics, Jamica, N.Y.
75608	Linden and Co, Providence, R.I.
75915	Littelfuse, Inc, Des Plaines, Ill. 60016
76005	Lord Mfg Co, Erie, Penn. 16512
76149	Mallory Electric Corp, Detroit, Mich. 48204
76487	James Millen Mfg Co, Malden, Mass. 02148
76545	Mueller Electric Co, Cleveland, Ohio 44114
76684	National Tube Co, Pittsburg, Penn.
76854	Oak Mfg Co, Crystal Lake, Ill.
77147	Patton MacGuyer Co, Providence, R.I.
77166	Pass-Seymour, Syracuse, N.Y.
77263	Pierce Roberts Rubber Co, Trenton, N.J.
77339	Positive Lockwasher Co, Newark, N.J.
77642	Ray-O-Vac Co, Madison, Wisc.
77630	TRW, Electronic Comp, Camden, N.J. 08103
77638	General Instruments Corp, Brooklyn, N.Y.
78189	Shakeproof (Ill. Tool Works), Elgin, Ill. 60120
78277	Sigma Instruments Inc, S.Braintree, Mass.
78488	Stackpole Carbon Co, St. Marys, Penn.
78553	Tinnerman Products, Inc, Cleveland, Ohio
79089	RCA, Rec Tube & Semicond, Harrison, N.J.
79725	Wiremold Co, Hartford, Conn. 06110
79963	Zierick Mfg Co, New Rochelle, N.Y.
80030	Prestole Fastener, Toledo, Ohio
80048	Vickers Inc, St. Louis, Mo.
80131	Electronic Industries Assoc, Washington, D.C.
80183	Sprague Products Co, No. Adams, Mass.
80211	Motorola Inc, Franklin Park, Ill. 60131
80258	Standard Oil Co, Lafeyette, Ind.
80294	Bourns Inc, Riverside, Calif. 92506
80431	Air Filter Corp, Milwaukee, Wisc. 53218
80583	Hammerlund Co, Inc, New York, N.Y.
80740	Beckman Instruments, Inc, Fullerton, Calif.
81030	International Insturment, Orange, Conn.
81073	Grayhill Inc, LaGrange, Ill. 60525
81143	Isolantite Mfg Corp, Stirling, N.J. 07980
81349	Military Specifications
81350	Joint Army-Navy Specifications
81751	Columbus Electronics Corp, Yonkers, N.Y.
81831	Filtron Co, Flushing, L.I., N.Y. 11354
81840	Ledex Inc, Dayton, Ohio 45402
81860	Berry-Wright Corp, Watertown, Mass.
82219	Sylvania Elec Prod, Emporium, Penn.
82273	Indiana Pattern & Model Works, LaPort, Ind.
82389	Switchcraft Inc, Chicago, Ill. 60630
82647	Metals & Controls Inc, Attleboro, Mass.
82807	Milwaukee Resistor Co, Milwaukee, Wisc.
83033	Meissner Mfg, (Maguire Ind) Mt. Carmel, Ill.
83058	Carr Fastener Co, Cambridge, Mass.
83186	Victory Engineering, Springfield, N.J. 07081
83361	Bearing Specialty Co, San Francisco, Calif.
83587	Solar Electric Corp, Warren, Penn.
83740	Union Carbide Corp, New York, N.Y. 10017
83781	National Electronics Inc, Geneva, Ill.
84411	TRW Capacitor Div, Ogallala, Nebr.
84835	Lehigh Metal Prods, Cambridge, Mass. 02140
84971	TA Mfg Corp, Los Angeles, Calif.
86577	Precision Metal Prods, Stoneham, Mass. 02180
86684	RCA (Elect. Comp & Dev), Harrison, N.J.
86687	REC Corp, New Rochelle, N.Y. 10801
86800	Cont Electronics Corp, Brooklyn, N.Y. 11222
88140	Cutler-Hammer Inc, Lincoln, Ill.
88219	Gould Nat. Batteries Inc, Trenton, N.J.
88419	Cornell-Dubilier, Fuquay-Varina, N.C.
88627	K & G Mfg Co, New York, N.Y.
89482	Holtzer-Cabot Corp, Boston, Mass.
89665	United Transformer Co, Chicago, Ill.
90201	Mallory Capacitor Co, Indianapolis, Ind.
90750	Westinghouse Electric Corp, Boston, Mass.
90952	Hardware Products Co, Reading, Penn. 19602
91032	Continental Wire Corp, York, Penn. 17405
91146	ITT (Cannon Electric Inc), Salem, Mass.
91293	Johanson Mfg Co, Boonton, N.J. 07005
91506	Augat Inc, Attleboro, Mass. 02703
91598	Chandler Co, Wethersfield, Conn. 06109
91637	Dale Electronics Inc, Columbus, Nebr.
91662	Elco Corp, Willow Grove, Penn.
91719	General Instruments, Inc, Dallas, Texas
91929	Honeywell Inc, Freeport, Ill.
92519	Electra Insul Corp, Woodside, L.I., N.Y.
92678	E.G.&G., Boston, Mass.
93332	Sylvania Elect Prods, Inc, Woburn, Mass.
93916	Cramer Products Co, New York, N.Y. 10013
94144	Raytheon Co, Components Div, Quincy, Mass.
94154	Tung Sol Electric Inc, Newark, N.J.
95076	Garde Mfg Co, Cumberland, R.I.
95121	Quality Components Inc, St. Mary's, Penn.
95146	Alco Electronics Mfg Co, Lawrence, Mass.
95238	Continental Connector Corp, Woodside, N.Y.
95275	Vitramon, Inc, Bridgeport, Conn.
95354	Methode Mfg Co, Chicago, Ill.
95412	General Electric Co, Schenectady, N.Y.
95794	Anaconda Amer Brass Co, Torrington, Conn.
96095	Hi-Q Div. of Aerovox Corp, Orlean, N.Y.
96214	Texas Instruments Inc, Dallas, Texas 75209
96330	Thordarson-Meissner, Mt. Carmel, Ill.
96341	Microwave Associates Inc, Burlington, Mass.
96791	Amphenol Corp, Jonesville, Wisc, 53545
96906	Military Standards
98291	Sealectro Corp, Mamaroneck, N.Y. 10544
98474	Compar Inc, Burlingame, Calif.
98821	North Hills Electronics Inc, Glen Cove, N.Y.
99180	Transitron Electronics Corp, Melrose, Mass.
99313	Varian, Palo Alto, Calif. 94303
99378	Atlee Corp, Winchester, Mass. 01890
99800	Delevan Electronics Corp, E. Aurora, N.Y.

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MECHANICAL PARTS LIST

Figure 7-1 Reference	Description	GR Part Number	Fed. Mfg. Code	Mfg. Part No.	Fed. Stock No.
FRONT PANEL					
1	Handle	5360-2017	24655	5360-2017	
2, 3	Meter Cover, ME6-701, light gray	5720-6713	91929	ME-6	
4	Knob, Calibrate, includes retainer (P/N 5220-5402)	5520-5320	24655	5520-5320	
5, 6, 7	Knob, Frequency, Measurement,	5500-5321	24655	5500-5321	
15, 16, 17	Input, Full Scale (for ΔZ) Test Voltage, Full Scale (for ΔO), includes retainer (P/N 5220-5402				
8, 9, 13, 14	Jack, Standard, Unknown, GR874	0874-4504	24655	0874-4504	
10, 11, 12	Jack, Guard, Ground, Guard	4150-3200	24655	4150-3200	
18	Switch, Toggle, Power/Off	7910-1300	04009	83053-SA	5930-909-3510
19	Nut, Dress, 15/32-32, 7/16	5800-0800	24655	5800-0800	5310-344-3634
REAR PANEL					
1	Fuse Holder (2), Fuse-Mounting Device	5650-0100	71400	HKP-H	5920-284-7144
2	Power Plug, PL501	4240-0600	24655	4240-0600	5935-816-0254
3, 4	Slide Switch, Line-Voltage (S502) and Magnitude Linearizer (S908)	7910-0831	42190	4603	
5	Socket, Analog Limit Comparator, (SO909)	4230-5406	02660	126-198	
6	Socket, Analog Voltage Output (SO910)	4230-5405	126-198		
7	Slide Switch, Start (S904)	7910-0774	76854	#78	
8	Jack, Start (J908)	4260-1030	82389	#111	
9	Nut, dress, 3/8-32, 7/16	5800-0805	24655	5800-0805	
10	Cover Plate	1654-8210	24655	1654-8210	

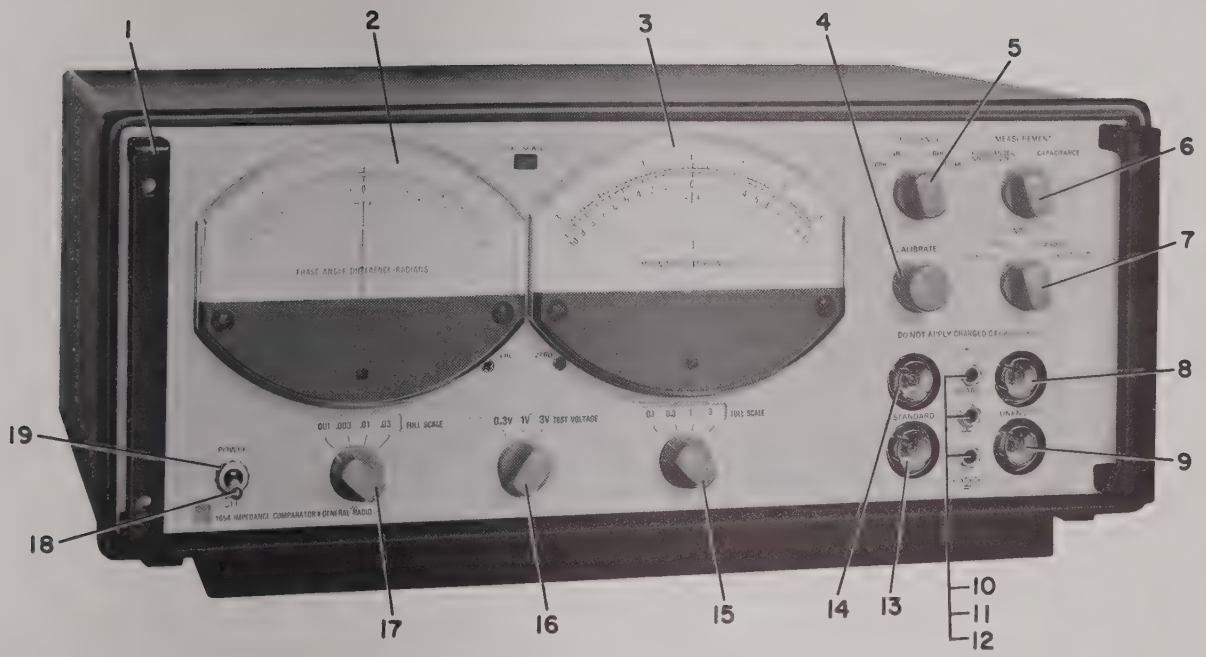


Figure 7-1. Front-panel mechanical parts on the 1654 (refer to parts list).

Figure 7-2. Rear-panel mechanical parts on the 1654 (refer to parts list).

ELECTRICAL PARTS LIST

Ref. No.	Description	GR Part No.	Fed. Mfg. Code	Mfg. Part No.	Fed. Stock No.
CAPACITORS					
C101	Ceramic 680 pF +80-20% 500 V	4404-1689	72982	831, 680 pF +80-20%	
C102	Electrolytic 15 μF +150-10% 15 V	4450-3700	37942	TT, 15 μF 15 V	
C103	Electrolytic 15 μF +150-10% 15 V	4450-3700	37942	TT, 15 μF 15 V	
C104	Plastic .1 μF ±2% 100 V	4860-8251	84411	663 UW, .1 μF ±2% 100 V	
C105	Mica .01 μF ±1% 500 V	4750-0100	00656	1464, .01 μF	5910-087-7593
C106	Mica .001 μF ±2% 300 V	4690-4200	88419	CM20E, 1000 pF ±2%	5910-669-3241
C107	Mica .00105 μF ±2% 100 V	4700-0688	14655	22A, .00105 μF ±2%	
C108	Electrolytic 15 μF +150-10% 15 V	4450-3700	37942	TT, 15 μF 15 V	
C109	Electrolytic 15 μF +150-10% 15 V	4450-3700	37942	TT, 15 μF 15 V	
C110	Mica 30 pF ±10% 500 V	4620-0650	72136	CM15, 30 pF ±10%	
C111	Electrolytic 15 μF +150-10% 15 V	4450-3700	37942	TT, 15 μF 15 V	
C112	Electrolytic 60 μF +150-10% 25 V	4450-2900	56289	D17872	5910-799-9280
C113	Electrolytic 60 μF +150-10% 25 V	4450-2900	56289	D17872	5910-799-9280
C114	Electrolytic 2000 μF +150-10% 6 V	4450-6106	37942	TT, 2000 μF +150-10%	
DIODES					
CR101	Type 1N645	6082-1016	24446	1N645	5961-944-8222
CR102	Type 1N645	6082-1016	24446	1N645	5961-944-8222
CR103	Type 1N4009	6082-1012	24446	1N4009	5961-892-8700
CR104	Type 1N645	6082-1016	24446	1N645	5961-944-8222
CR105	Type 1N645	6082-1016	24446	1N645	5961-944-8222
RESISTORS					
R101	Film 15.9 kΩ ±1% 1/8 W	6250-2159	75042	CEA, 15.9 kΩ ±1%	
R102	Composition 12 kΩ ±5% 1/4 W	6099-3125	75042	BTS, 12 kΩ ±5%	
R103	Composition 51 kΩ ±5% 1/4 W	6099-3515	75042	BTS, 51 kΩ ±5%	5905-200-6731
R104	Composition 68 Ω ±5% 1/4 W	6099-0685	75042	BTS, 68 Ω ±5%	
R105	Composition 330 Ω ±5% 1/4 W	6099-1335	75042	BTS, 330 Ω ±5%	5905-686-3369
R106	Composition 18 kΩ ±5% 1/4 W	6099-3185	75042	BTS, 18 kΩ ±5%	5905-687-0000
R107	Composition 430 Ω ±5% 1/4 W	6099-1435	75042	BTS, 430 Ω ±5%	
R108	Composition 1.8 kΩ ±10% 1/4 W	6099-2189	75042	BTS, 1.8 kΩ ±10%	
R109	Composition 430 Ω ±5% 1/4 W	6099-1435	75042	BTS, 430 Ω ±5%	
R110	Thermistor 100 kΩ ±20%	6740-2021	83186	51A161GR	5905-933-8183
R111	Pot. Wire Wound 2 kΩ ±10%	6056-0100	11236	115, 2 kΩ ±10%	
R112	Pot. Wire Wound 2 kΩ ±10%	6056-0100	11236	115, 2 kΩ ±10%	
R113	Pot. Wire Wound 2 kΩ ±10%	6056-0100	11236	115, 2 kΩ ±10%	
R114	Pot. Wire Wound 100 Ω ±10%	6056-0132	11236	115, 100 Ω ±10%	
R115	Film 15 kΩ ±1% 1/8 W	6250-2150	75042	CEA, 15 kΩ ±1%	5905-581-7626
R116	Film 1.21 kΩ ±1% 1/8 W	6250-1121	75042	CEA, 1.21 kΩ ±1%	
R117	Composition 1 kΩ ±10% 1/4 W	6099-2109	75042	BTS, 1 kΩ ±10%	
R118	Composition 4.7 kΩ ±5% 1/4 W	6099-2475	75042	BTS, 4.7 kΩ ±5%	5905-686-9998
R119	Composition 2.7 kΩ ±5% 1/4 W	6099-2275	75042	BTS, 2.7 kΩ ±5%	
R120	Composition 3.9 kΩ ±5% 1/4 W	6099-2395	75042	BTS, 3.9 kΩ ±5%	
R121	Composition 1.1 kΩ ±5% 1/4 W	6099-2115	75042	BTS, 1.1 kΩ ±5%	
R122	Composition 68 kΩ ±5% 1/4 W	6099-3685	75042	BTS, 68 kΩ ±5%	5905-681-8853
R123	Composition 470 Ω ±10% 1/4 W	6099-1479	75042	BTS, 470 Ω ±5%	
R124	Composition 3.9 kΩ ±5% 1/4 W	6099-2395	75042	BTS, 3.9 kΩ ±5%	
R125	Composition 62 Ω ±5% 1/2 W	6100-0625	01121	RC20GF620J	5905-279-1760
R126	Composition 62 Ω ±5% 1/2 W	6100-0625	01121	RC20GF620J	5905-279-1760
R127	Composition 3.9 kΩ ±5% 1/4 W	6099-2395	75042	BTS, 3.9 kΩ ±5%	
R128	Composition 2.2 kΩ ±5% 1/4 W	6099-2225	75042	BTS, 2.2 kΩ ±5%	5905-723-5251
R129	Composition 330 Ω ±5% 1/4 W	6099-1335	75042	BTS, 330 kΩ ±5%	5905-686-3369
R130	Thermistor 200 Ω ±10%	6740-1600	02606	KB22J1	
R131	Composition 180 Ω ±5% 1/4 W	6099-1185	75042	BTS, 180 Ω ±5%	5905-279-5476
R132	Thermistor 200 Ω ±10%	6740-1600	02606	KB22J1	
R133	Composition 12 Ω ±5% 1/4 W	6099-0125	75042	BTS, 12 Ω ±5%	5905-279-5455
R134	Thermistor 50 Ω ±10%	6740-1900	02606	CB15L1	
R135	Composition 10 Ω ±10% 1/4 W	6099-0109			
TRANSISTORS					
Q101	Type 2N4123	8210-1123	93916	2N4123	
Q102	Type 2N4123	8210-1123	93916	2N4123	
Q103	Type 2N4125	8210-1125	93916	2N4125	
Q104	Type 2N3414	8210-1047	24446	2N3416	5961-989-2749
Q105	Type 2N3414	8210-1047	24446	2N3416	5961-989-2749
Q106	Type 2N4125	8210-1125	93916	2N4125	
Q107	Type 2N697	8210-1040	82219	2N697	5961-752-0150
Q108	Type 2N1131	8210-1025	96214	2N1131	5960-788-8644

SIGNAL INDEX
OSCILLATOR ETCHED BOARD
(Reference Figures 7-3 and 7-4)

Signal	Description	Signal Type
PAO	Power-Amplifier Output	rms
GND	Signal Ground	
PAI	Power-Amplifier Input	dc and rms
+15 V	Power-Supply Voltage	dc
–15 V	Power-Supply Voltage	dc
OSIN	Oscillator Input	dc and rms
GND	Signal Ground	
OSO	Oscillator Output	dc and rms
OS1	100-Hz Oscillator-Network Output	dc and rms
OS2	1-kHz Oscillator-Network Output	dc and rms
OS3	10-kHz Oscillator-Network Output	dc and rms
OS4	100-kHz Oscillator-Network Output	dc and rms

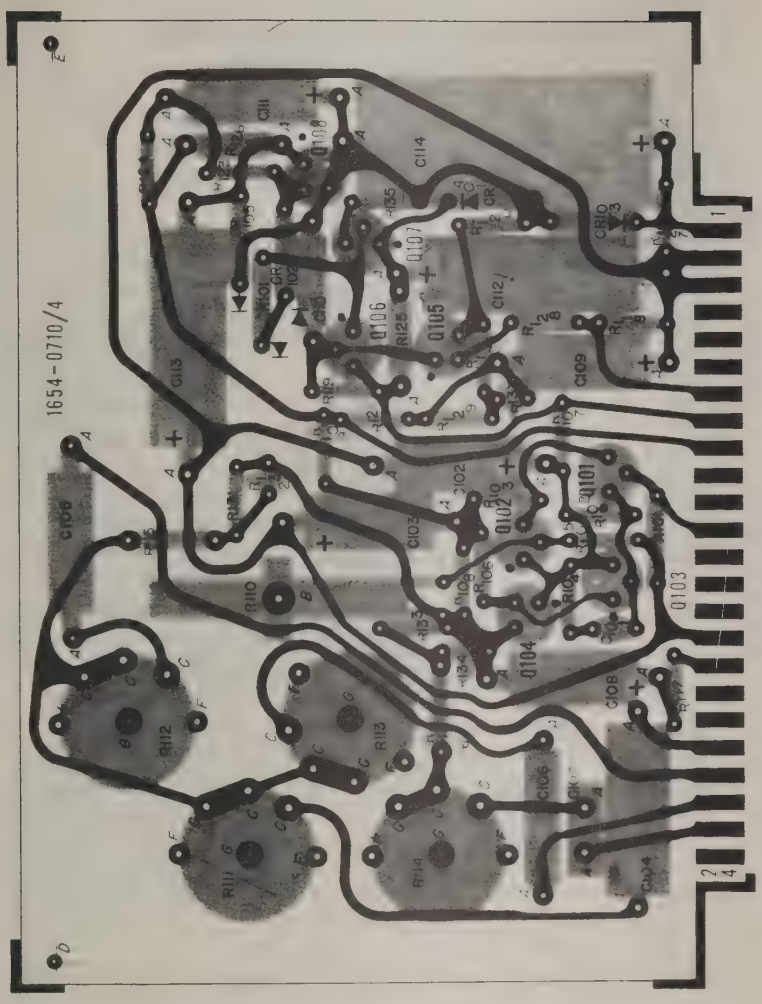
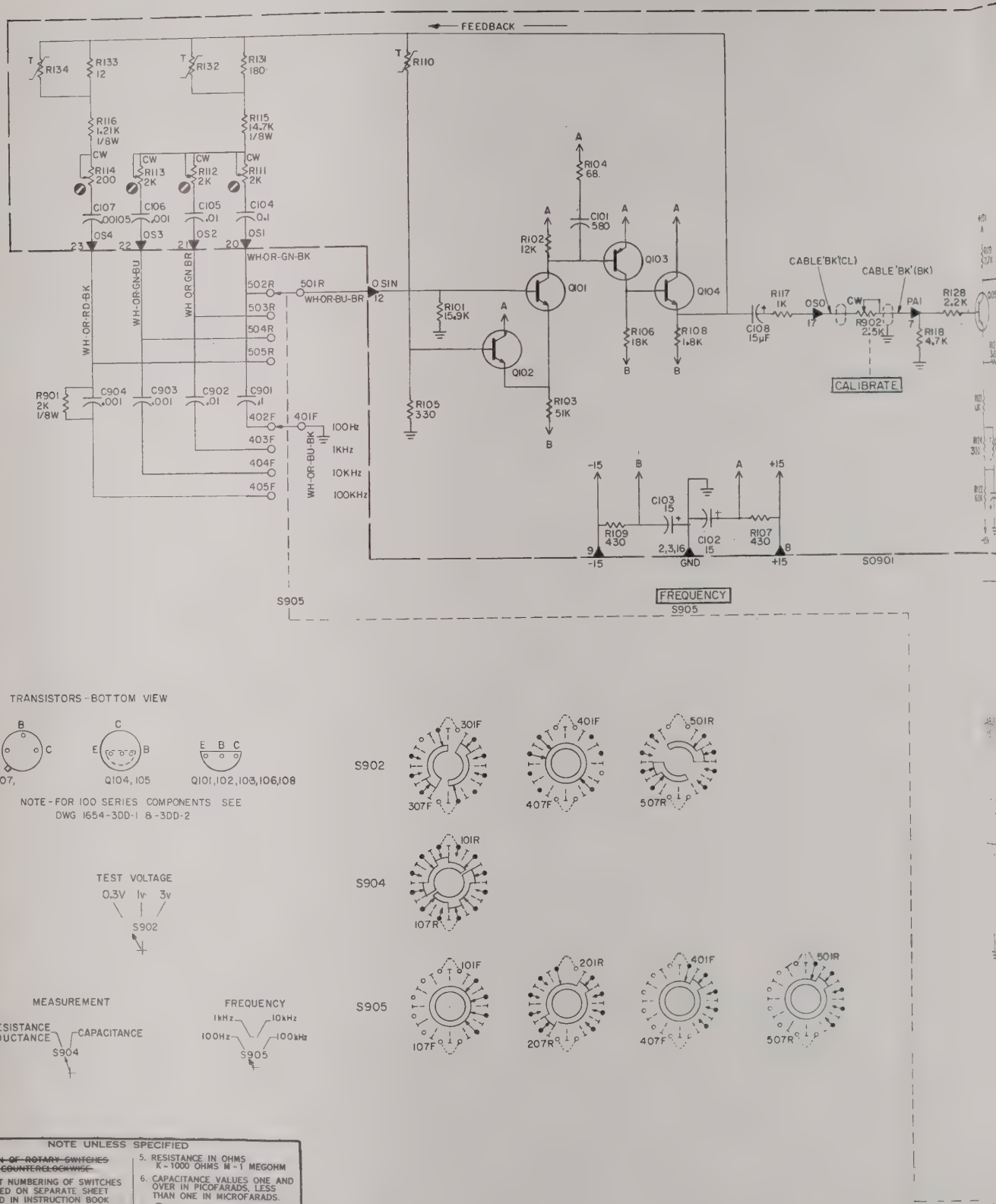


Figure 7-3. Oscillator-circuit etched-board assembly (P/N 1654-4711).

NOTE: The board is shown foil-side up. The number appearing on the foil side is *not* the part number. The dot on the foil at the transistor socket indicates the collector lead.



TRANSISTORS - BOTTOM VIEW

NOTE - FOR 100 SERIES COMPONENTS SEE DWG 1654-3DD-1 & -3DD-2

NOTE UNLESS SPECIFIED

~~POSITION OF ROTARY SWITCHES SHOWN COUNTERCLOCKWISE~~

CONTACT NUMBERING OF SWITCHES EXPLAINED ON SEPARATE SHEET SUPPLIED IN INSTRUCTION BOOK

REFER TO SERVICE NOTES IN INSTRUCTION BOOK FOR VOLTAGES APPEARING ON DIAGRAM

RESISTORS 1/4 WATT.

5. RESISTANCE IN OHMS K - 1000 OHMS M - 1 MEGOHM
6. CAPACITANCE VALUES ONE AND OVER IN PICOFARADS, LESS THAN ONE IN MICROFARADS.
7. ◯ KNOB CONTROL
8. ⊘ SCREWDRIVER CONTROL
9. AT - ANCHOR TERMINAL
10. TP - TEST POINT

Rotary switch sections are shown as viewed from the panel end of the shaft. The first digit of the contact number refers to the section. The section nearest the panel is 1, the next section back is 2, etc. The next two digits refer to the contact. Contact 01 is the first position clockwise from a strut screw (usually the screw above the locating key), and the other contacts are numbered sequentially (02, 03, 04, etc), proceeding clockwise around the section. A suffix F or R indicates that the contact is on the front or rear of the section, respectively.

SCHEMATIC DIAGRAM FOR OSCILLATOR & BRIDGE 1654 IMPEDANCE COMPARATOR

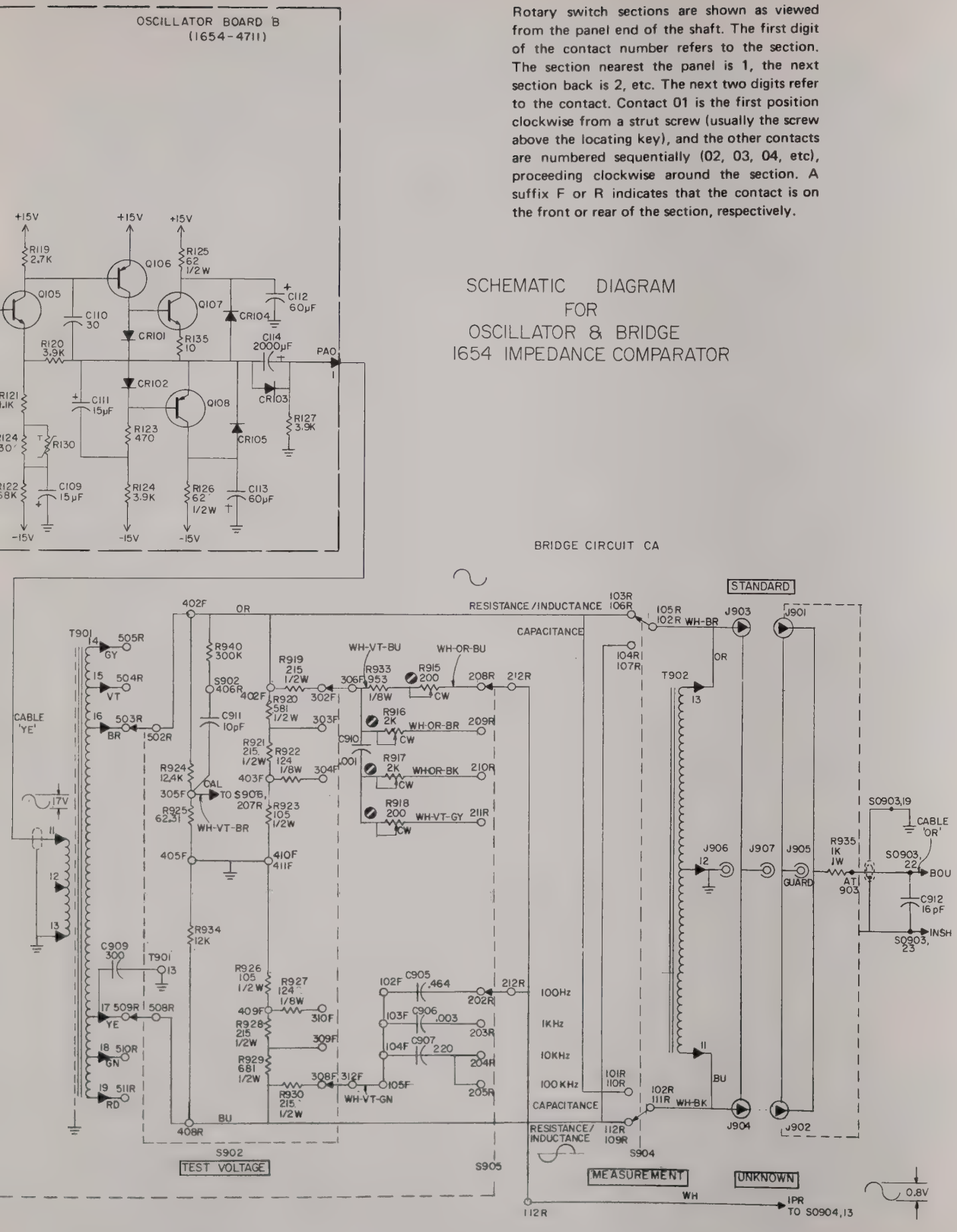


Figure 7-4. Oscillator and bridge-circuit schematic diagram.

ELECTRICAL PARTS LIST

Ref. No.	Description	GR Part No.	Fed. Mfg. Code	Mfg. Part No.	Fed. Stock No.
CAPACITORS					
C301	Plastic .01 µF ±10% 400 V	4860-7648	84411	663 UW, .01 µF ±10%	
C302	Electrolytic 100 µF +150-10% 15 V	4450-2800	56289	D17872	5910-034-5368
C303	Electrolytic 100 µF +150-10% 15 V	4450-2800	56289	D17872	5910-034-5368
C304	Plastic 0.047 ±10% 200 V	4860-7869	84411	663 UW, 0.047 µF ±10% 200 V	
C305	Electrolytic 18 µF ±20% 15 V	4450-5230	56289	150D186X0015B2	
C306	Electrolytic 18 µF ±20% 15 V	4450-5230	56289	150D186X0015B2	
C307	Ceramic 330 pF ±10% 500 V	4404-1338	72982	831, 330 pF ±10%	5910-974-5702
C308	Mica 39 pF ±5% 500 V	4640-0200	72136	CM, 39 pF ±5%	
C309	Electrolytic 18 µF ±20% 15 V	4450-5230	56289	150D186X0015B2	
C310	Plastic 0.1 µF ±10% 200 V	4862-8050	84411	GR-19, 0.1 µF ±10%	
C311	Ceramic .0018 µF ±10% 500 V	4406-2188	72982	811, 1800 pF ±10%	
C312	Plastic 0.68 µF ±10% 200 V	4862-8340	84411	GR-19, 0.68 µF ±10%	
C313	Electrolytic 100 µF +150-10% 15 V	4450-2800	56289	D17872	5910-034-5368
C314	Ceramic .001 µF +80-20% 500 V	4404-2109	72982	831, .001 µF +80-20%	5910-983-9994
C315	Ceramic .001 µF +80-20% 500 V	4404-2109	72982	831, .001 µF +80-20%	5910-983-9994
C316	Electrolytic 15 µF +150-10% 15 V	4450-3700	37942	TT, 15 µF 15 V	
C317	Electrolytic 15 µF +150-10% 15 V	4450-3700	37942	TT, 15 µF 15 V	
C318	Plastic 0.1 µF ±2% 100 V	4860-8251	84411	663 UW, 0.1 µF ±2% 100 V	
C319	Mica .001 µF ±2% 300 V	4690-4200	88419	CM20E, 1000 pF ±2%	5910-669-3241
C320	Mica .01 µF ±2% 300 V	4780-0300	88419	CM35E, .01 µF ±2%	
C321	Ceramic 2.2 pF ±10% 500 V	4400-0200	78488	GA, 2.2 pF ±10%	
RESISTORS					
R301	Film 47.5 kΩ ±1% 1/8 W	6250-2475	75042	CEA, 47.5 kΩ ±1%	5905-577-6747
R302	Composition 470 Ω ±10% 1/4 W	6099-1479	75042	BTS, 470 Ω ±10%	
R303	Composition 1.5 mΩ ±5% 1/2 W	6100-5155	01121	RC20GF155J	5905-279-1754
R304	Composition 1 mΩ ±5% 1/4 W	6099-5105	75042	BTS, 1 mΩ ±5%	
R305	Composition 470 Ω ±10% 1/4 W	6099-1479	75042	BTS, 470 Ω ±10%	
R306	Composition 22 mΩ ±5% 1/2 W	6100-6225	01121	RC20GF226J	5905-259-2990
R307	Composition 39 kΩ ±10% 1/4 W	6099-3399	75042	BTS, 39 kΩ ±10%	
R308	Composition 47 kΩ ±5% 1/4 W	6099-3475	75042	BTS, 47 kΩ ±5%	5905-683-2246
R309	Composition 47 kΩ ±5% 1/4 W	6099-3475	75042	BTS, 47 kΩ ±5%	5905-683-2246
R310	Composition 1 kΩ ±5% 1/4 W	6099-2105	75042	BTS, 1 kΩ ±5%	5905-681-6462
R311	Composition 30 kΩ ±5% 1/4 W	6099-3305	75042	BTS, 30 kΩ ±5%	5905-803-2908
R312	Composition 6.8 kΩ ±10% 1/4 W	6099-2689	75042	BTS, 6.8 kΩ ±10%	
R313	Composition 68 Ω ±5% 1/4 W	6099-0685	75042	BTS, 68 Ω ±5%	
R314	Composition 12 kΩ ±10% 1/4 W	6099-3129	75042	BTS, 12 kΩ ±5%	
R315	Composition 3.9 kΩ ±5% 1/4 W	6099-2395	75042	BTS, 3.9 kΩ ±5%	
R316	Composition 100 kΩ ±5% 1/4 W	6099-4105	75042	BTS, 100 kΩ ±5%	5905-686-3129
R317	Composition 10 kΩ ±5% 1/4 W	6099-3105	75042	BTS, 10 kΩ ±5%	5905-683-2238
R318	Composition 10 Ω ±10% 1/4 W	6099-0109	75042	BTS, 10 Ω ±10%	
R319	Composition 1 kΩ ±5% 1/2 W	6100-2105	01121	RC20GF102J	5905-195-6806
R320	Composition 62 kΩ ±5% 1/4 W	6099-3625	75042	BTS, 62 kΩ ±5%	
R321	Composition 27 kΩ ±5% 1/4 W	6099-3275	75042	BTS, 27 kΩ ±5%	5905-683-3838
R322	Composition 220 kΩ ±10% 1/4 W	6099-4229	75042	BTS, 220 Ω ±10%	
R323	Composition 100 Ω ±10% 1/4 W	6099-1109	75042	BTS, 100 Ω ±10%	
R324	Film 3.32 kΩ ±1% 1/8 W	6250-1332	75042	CEA, 3.32 kΩ ±1%	
R325	Composition 20 kΩ ±5% 1/4 W	6099-3205	75042	BTS, 20 kΩ ±5%	5905-686-3368
R326	Film 33.2 kΩ ±1% 1/8 W	6250-2332	75042	CEA, 33.2 kΩ ±1%	5905-681-8758
R327	Composition 3.3 kΩ ±10% 1/4 W	6099-2339	75042	BTS, 3.3 kΩ ±10%	
R328	Composition 24 kΩ ±5% 1/4 W	6099-3245	75042	BTS, 24 kΩ ±5%	
R329	Composition 3.9 kΩ ±5% 1/4 W	6099-2395	75042	BTS, 3.9 kΩ ±5%	
R330	Composition 100 Ω ±10% 1/4 W	6099-1109	75042	BTS, 100 Ω ±10%	
R331	Film 3.32 kΩ ±1% 1/8 W	6250-1332	75042	CEA, 3.32 kΩ ±1%	
R332	Film 20 kΩ ±1% 1/8 W	6250-2200	75042	CEA, 20 kΩ ±1%	5905-702-5971
R333	Composition 3 kΩ ±5% 1/4 W	6099-2305	75042	BTS, 3 kΩ ±5%	5905-682-4097
R334	Film 10 kΩ ±1% 1/8 W	6250-2100	75042	CEA, 10 kΩ ±1%	5905-883-4847
R335	Composition 110 kΩ ±5% 1/4 W	6099-4115	75042	BTS, 110 kΩ ±5%	
R336	Composition 15 kΩ ±10% 1/4 W	6099-3159	75042	BTS, 15 kΩ ±10%	
R337	Composition 100 Ω ±10% 1/4 W	6099-1109	75042	BTS, 100 Ω ±10%	
R338	Film 10 kΩ ±1% 1/8 W	6250-2100	75042	CEA, 10 kΩ ±1%	5905-883-4847
R339	Film 33 kΩ ±5% 1/4 W	6099-3335	75042	BTS, 33 kΩ ±5%	
R340	Film 2 kΩ ±5% 1/4 W	6099-2205	75042	BTS, 2 kΩ ±5%	5905-279-4629
R341	Film 130 Ω ±5% 1/4 W	6099-1135	75042	BTS, 130 Ω ±5%	5905-807-6269
R342	Film 130 Ω ±5% 1/4 W	6099-1135	75042	BTS, 130 Ω ±5%	5905-807-6269
R343	Pot. Wire Wound 2 kΩ ±10% 1 W	6051-2209	07990	2600 PC, 2 kΩ ±10%	
R344	Pot. Wire Wound 1 kΩ ±10% 1 W	6051-2109	02660	2600-PC, 1 kΩ ±10%	
R345	Composition 300 Ω ±5% 1/4 W	6099-1305	75042	BTS, 300 Ω ±5%	5905-279-5481
R346	Film 15 kΩ ±1% 1/8 W	6250-2150	75042	CEA, 15 kΩ ±1%	5905-581-7626
R347	Pot. Wire Wound 1 kΩ ±10% 1 W	6051-2109	02660	2600-PC, 1 kΩ ±10%	
R348	Pot. Wire Wound 200 Ω ±10% 1 W	6051-1209	96791	2600-PC 200 Ω ±10%	
R349	Film 1.47 kΩ ±1% 1/4 W	6350-1147	75042	CEB, 1.47 kΩ ±1%	5905-577-6733

ELECTRICAL PARTS LIST (cont)

Ref. No.	Description	GR Part No.	Fed. Mfg. Code	Mfg. Part No.	Fed. Stock No.
TRANSISTORS					
Q301	Type 2N4220	8210-1143	93916	2N4220	
Q302	Type 2N4250	8210-1135	93916	2N4250	
Q303	Type 2N4123	8210-1123	93916	2N4123	
Q304	Type 2N4250	8210-1135	93916	2N4250	
Q305	Type 2N4123	8210-1123	93916	2N4123	
Q306	Type 2N4250	8210-1135	93916	2N4250	
Q307	Type 2N4250	8210-1135	93916	2N4250	
Q308	Type 2N4123	8210-1123	93916	2N4123	
Q309	Type 2N4125	8210-1125	93916	2N4125	
Q310	Type 2N4123	8210-1123	93916	2N4123	
Q311	Type 2N4123	8210-1123	93916	2N4123	
Q312	Type 2N4125	8210-1125	93916	2N4125	
Q313	Type 2N4123	8210-1123	93916	2N4123	
Q314	Type 2N4123	8210-1123	93916	2N4123	
Q315	Type 2N4125	8210-1125	93916	2N4125	
Q316	Type 2N3414	8210-1047	24446	2N3416	5961-989-2749
MISCELLANEOUS					
CR301	Type IN4009 Diode	6082-1012	24446	1N4009	5961-892-8700
K301L	Relay Coil	6090-1131	24655	6090-1131	
K302L	Relay Coil	6090-1130	71707	XU-8242-P	
K301S	Relay Switch	6090-0800	30874	76586S	
K302S	Relay Switch	6090-0800	30874	76586S	

SIGNAL INDEX
UNBALANCE-AMPLIFIER ETCHED BOARD
(Reference Figures 7-5 and 7-6)

Signal	Description	Signal Type
GND	Signal Ground	
E90	90° Error-Signal Output	dc and rms
FO4	Input, 100-kHz Phase Shift	dc and rms
FO3	Input, 10-kHz Phase Shift	dc and rms
F91	Output, 100 Hz Phase Shift	dc and rms
F9A	Output, Phase-Shift Network	dc and rms
FO2	Input, 1-kHz Phase-Shift	dc and rms
+15 V	Power-Supply Voltage	dc
FO1	Input, 100-Hz Phase Shift	dc and rms
FOA	Input to Phase Shift and 0° Error-Signal Output	dc and rms
FLS	100-Hz Error-Signal Input	dc and rms
F92	Output, 10-kHz Phase Shift	dc and rms
FLA	100-Hz Error-Signal Output	dc and rms
GA1	Off-Scale, Relay-Signal Input	dc
F93	Output, 1-kHz Phase Shift	dc and rms
OVS	Off-Scale Signal Input	rms
PUF	Unregulated +15 V Power-Supply Voltage	dc
–15 V	Power-Supply Voltage	dc
GND	Signal Ground	
PRO	Bridge-Amplifier Output	rms
GUA	Guard Output Voltage	dc and rms
BOU	Bridge-Amplifier Input	rms
EXR	External Start-Relay Signal Input	dc

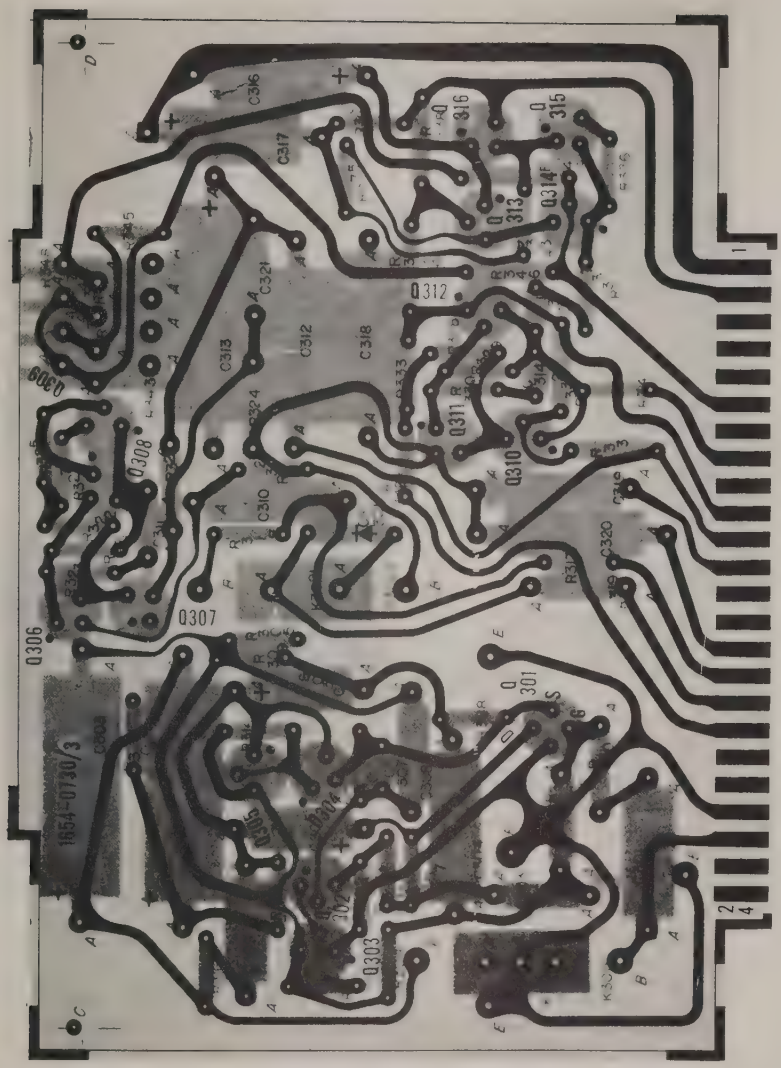
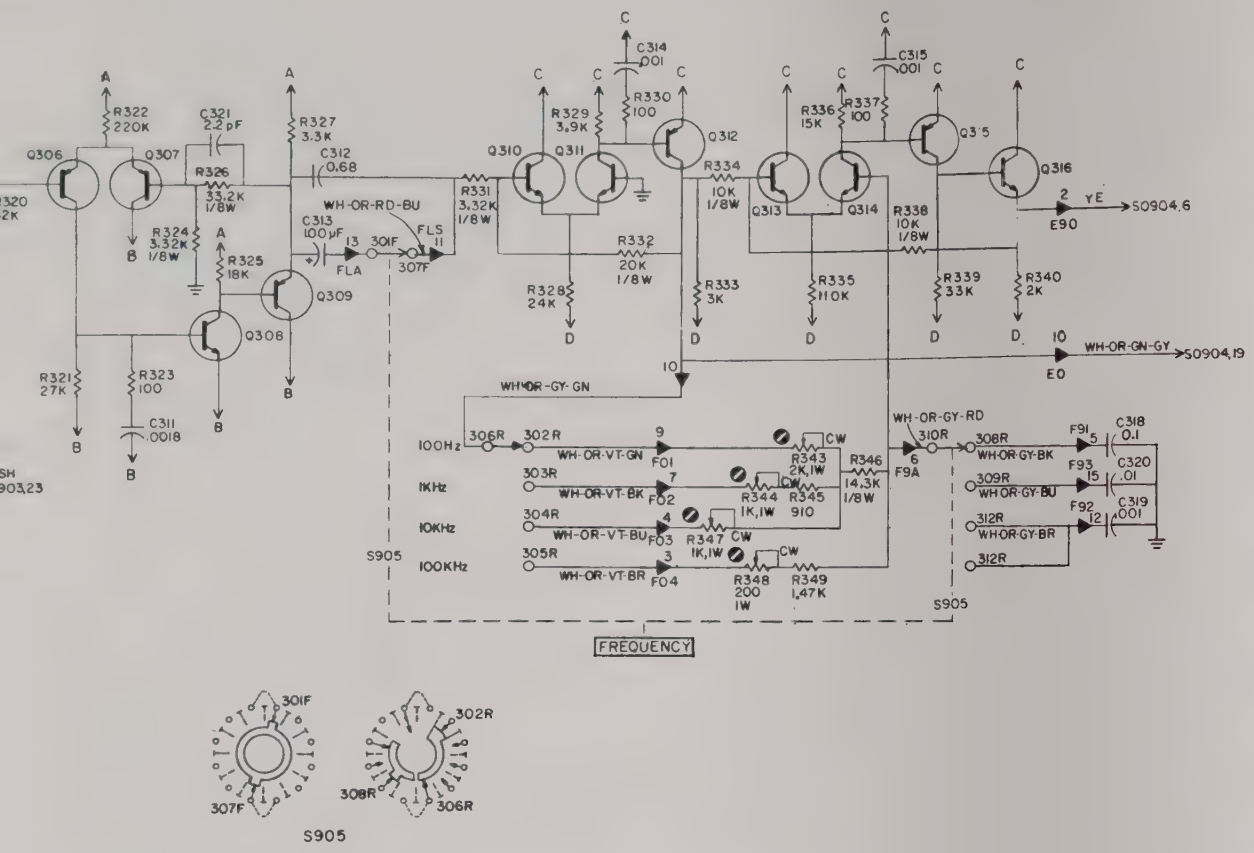


Figure 7-5. Unbalance-amplifier circuit etched-board assembly (P/N 1654-4731).

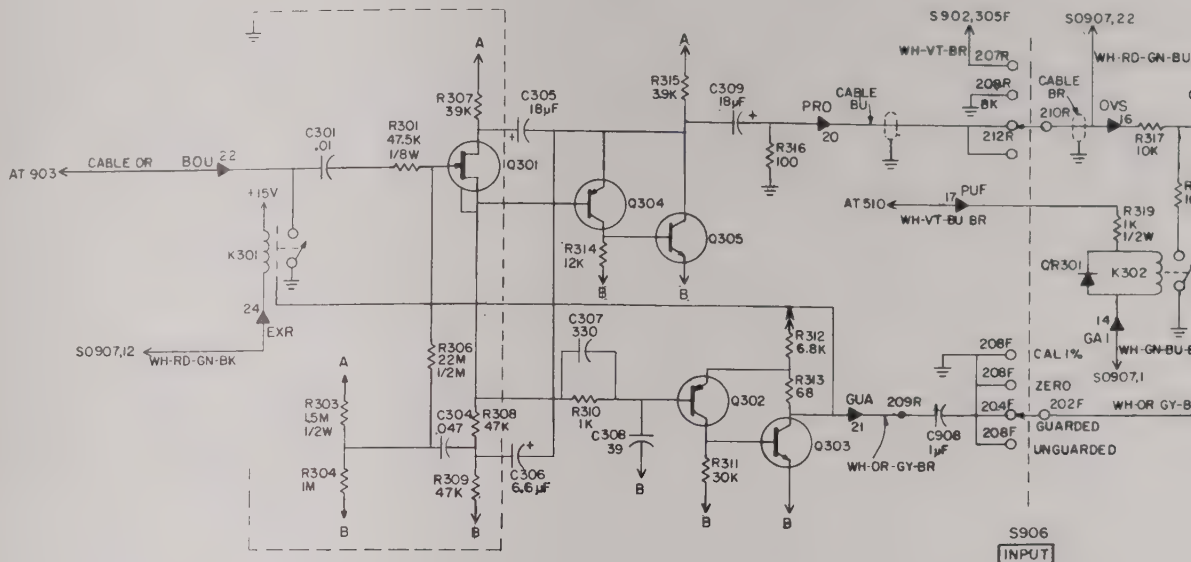
NOTE: The board is shown foil-side up. The number appearing on the foil side is *not* the part number. The dot on the foil at the transistor socket indicates the collector lead.

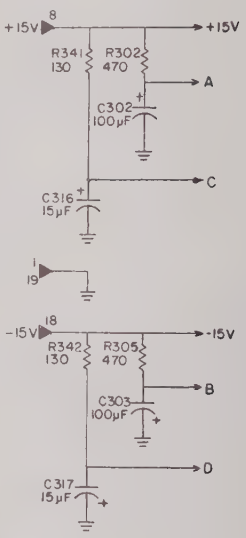


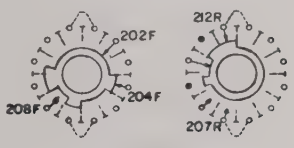
SCHEMATIC DIAGRAM
FOR
UNBALANCE AMPLIFIER (1654-4731)
1654 IMPEDANCE COMPARATOR

Rotary switch sections are shown as viewed from the panel end of the shaft. The first digit of the contact number refers to the section. The section nearest the panel is 1, the next section back is 2, etc. The next two digits refer to the contact. Contact 01 is the first position clockwise from a strut screw (usually the screw above the locating key), and the other contacts are numbered sequentially (02, 03, 04, etc), proceeding clockwise around the section. A suffix F or R indicates that the contact is on the front or rear of the section, respectively.

Figure 7-6. Unbalance-amplifier circuit schematic diagram.







S906

TRANSISTORS-BOTTOM VIEW

Q302,304,306, Q307 | Q316 | Q303,305,308, Q309, 310,311 Q312, 313,314, Q315 | Q301

NOTE UNLESS SPECIFIED

1. ~~POSITION OF ROTARY SWITCHES SHOWN COUNTERCLOCKWISE.~~
2. CONTACT NUMBERING OF SWITCHES EXPLAINED ON SEPARATE SHEET SUPPLIED IN INSTRUCTION BOOK.
3. REFER TO SERVICE NOTES IN INSTRUCTION BOOK FOR VOLTAGES APPEARING ON DIAGRAM.
4. RESISTORS 1/4 WATT.
5. RESISTANCE IN OHMS K - 1000 OHMS M - 1 MEGOHM
6. CAPACITANCE VALUES ONE AND OVER IN PICOFARADS, LESS THAN ONE IN MICROFARADS.
7. ○ KNOB CONTROL
8. ● SCREWDRIVER CONTROL
9. AT - ANCHOR TERMINAL
10. TP - TEST POINT

ELECTRICAL PARTS LIST (cont)

Ref. No.	Description	GR Part No.	Fed. Mfg. Code	Mfg. Part No.	Fed. Stock No.
CAPACITORS					
C401	Mica .001 µF ±2% 300 V	4690-4200	88419	CM20E, 1000 pF ±2%	
C403	Electrolytic 68 µF ±20% 15 V	4450-5615	80183	150D686X0015R2	
C404	Electrolytic 68 µF ±20% 15 V	4450-5615	80183	150D686X0015R2	
C405	Ceramic .02 µF +80-20% 50 V	4402-3200	01121	35-203W	5910-952-8659
C406	Ceramic .02 µF +80-20% 50 V	4402-3200	01121	35-203W	5910-952-8659
C407	Electrolytic 15 µF +150-10% 15 V	4450-3700	37942	TT, 15 µF 15 V	
C408	Ceramic .05 µF +80-20% 50 V	4403-3500	01121	40-503W	5910-883-7321
C409	Ceramic .05 µF +80-20% 50 V	4403-3500	01121	40-503W	5910-883-7321
C410	Mica 13 pF ±5% 500 V	4640-0093	72136	CM15, 13 pF ±5%	
C411	Trimmer 1-4.5 pF	4910-1103	24655	4910-1103	
C412	Plastic .75 pF ±5% 100 V	4860-8006	84411	663 UW, .75 pF ±5% 100 V	
C413	Plastic .464 µF ±2% 100 V	4860-7990	84411	663 UW, .464 µF ±1% 100 V	5910-902-5191
C414	Ceramic .01 µF +80-20% 50 V	4401-3100	80131	CC61, .01 µF +80-20%	5910-974-5694
C415	Electrolytic 6.8 µF +20% 35 V	4450-5000	56289	150D685X0035B2	5910-814-5869
C416	Electrolytic 6.8 µF ±20% 35 V	4450-5000	56289	150D685X0035B2	5910-814-5869
C417	Mica 13 pF ±5% 500 V	4640-0093	72136	CM15, 13 pF ±5%	
C418	Trimmer 1-4.5 pF	4910-1103	24655	4910-1103	
C419	Plastic .75 pF ±5% 100 V	4860-8006	84411	663 UW, .75 pF ±5% 100 V	
C420	Plastic .464 µF ±2% 100 V	4860-7990	84411	663 UW, .464 µF ±1% 100 V	5910-902-5191
C421	Ceramic .01 µF +80-20% 50 V	4401-3100	80131	CC61 .01 µF +80-20%	5910-974-5697
C422	Ceramic 100 pF +80-20% 500 V	4404-1109	72982	831, 100 pF +80-20%	
C423	Ceramic 0.1 µF +80-20% 50 V	4403-4100	80131	CC63, .1 µF +80-20%	5910-811-4788
C424	Plastic .68 µF ±10% 100 V	4860-8008	77630	663 UW, .68 µF ±10%	5910-931-0533
C425	Plastic .68 µF ±10% 100 V	4860-8008	77630	663 UW, .68 µF ±10%	5910-931-0533
DIODES					
CR401	Type 1N759A	6083-1014	81349	1N759A	5961-846-9157
CR402	Type 1N753A	6083-1006	07910	1N753A	5961-752-6121
CR403	Type 1N4009	6082-1012	24446	1N4009	5961-892-8700
CR404	Type 1N4009	6082-1012	24446	1N4009	5961-892-8700
CR405	Type 1N4009	6082-1012	24446	1N4009	5961-892-8700
CR406	Type 1N4009	6082-1012	24446	1N4009	5961-892-8700
CR407	Type 1N4009	6082-1012	24446	1N4009	5961-892-8700
RESISTORS					
R401	Composition 1 mΩ ±5% 1/4 W	6099-5105	75042	BTS, 1 mΩ ±5%	
R402	Composition 3.3 kΩ ±10% 1/4 W	6099-2339	75042	BTS, 3.3 kΩ ±10%	
R403	Composition 47 kΩ ±5% 1/4 W	6099-3475	75042	BTS, 47 kΩ ±5%	5905-683-2246
R404	Composition 3.3 kΩ ±5% 1/4 W	6099-2335	75042	BTS, 3.3 kΩ ±5%	5905-577-0627
R405	Composition 39 kΩ ±10% 1/4 W	6099-3399	75042	BTS, 39 kΩ ±10%	
R406	Composition 1.8 kΩ ±10% 1/4 W	6099-2185	75042	BTS, 1.8 kΩ ±5%	5905-688-3738
R407	Composition 300 Ω ±5% 1/4 W	6099-1305	75042	BTS, 300 Ω ±5%	5905-279-5481
R408	Composition 1 kΩ ±5% 1/4 W	6099-2105	75042	BTS, 1 kΩ ±5%	5905-681-6462
R409	Composition 820 Ω ±10% 1/4 W	6099-1829	75042	BTS, 820 Ω ±10%	
R410	Composition 1 kΩ ±5% 1/4 W	6099-2105	75042	BTS, 1 kΩ ±5%	5905-681-6462
R411	Composition 1 mΩ ±5% 1/4 W	6099-5105	75042	BTS, 1 mΩ ±5%	
R412	Composition 1 mΩ ±5% 1/4 W	6099-5105	75042	BTS, 1 mΩ ±5%	
R413	Composition 22 Ω ±10% 1/4 W	6099-0229	75042	BTS, 22 Ω ±10%	
R414	Composition 1 kΩ ±5% 1/4 W	6099-2105	75042	BTS, 1 kΩ ±5%	5905-681-6462
R415	Composition 22 Ω ±10% 1/4 W	6099-0229	75042	BTS, 22 Ω ±10%	
R416	Composition 4.7 kΩ ±5% 1/2 W	6100-2475	01121		
R417	Composition 1 kΩ ±10% 2 W	6120-2109	01121		
R418	Composition 10 kΩ ±5% 1/4 W	6099-3105	75042	BTS, 10 kΩ ±5%	5905-683-2238
R419	Composition 10 kΩ ±5% 1/4 W	6099-3105	75042	BTS, 10 kΩ ±5%	5905-683-2238
R420	Film 21 kΩ ±1% 1/2 W	6450-2210	75042	CEC, 21 kΩ ±1%	5905-581-1526
R421	Film 28.7 kΩ ±1% 1/4 W	6350-2287	75042	CEB, 48.7 kΩ ±1%	5905-542-7733
R422	Composition 3.9 kΩ ±5% 1/4 W	6099-2395	75042	BTS, 3.9 kΩ ±5%	
R423	Composition 10 kΩ ±5% 1/4 W	6099-3105	75042	BTS, 10 kΩ ±5%	5905-683-2238
R424	Composition 10 kΩ ±5% 1/4 W	6099-3105	75042	BTS, 10 kΩ ±5%	5905-683-2238
R425	Film 21 kΩ ±1% 1/2 W	6450-2210	75042	CEC, 21 kΩ ±1%	5905-581-1526
R426	Film 28.7 kΩ ±1% 1/4 W	6350-2287	75042	CEB, 28.7 kΩ ±1%	5905-733-9506
R427	Composition 3.9 kΩ ±5% 1/4 W	6099-2395	75042	BTS, 3.9 kΩ ±5%	
R428	Composition 2 kΩ ±5% 1/4 W	6099-2205	75042	BTS, 2 kΩ ±5%	5905-279-4629
R429	Composition 5.1 kΩ ±5% 1/4 W	6099-2515	75042	BTS, 5.1 kΩ ±5%	5905-279-4623
TRANSISTORS					
Q401	Type MPF103	8210-1157	04713	MPF-103	
Q402	Type 2N4125	8210-1125	93916	2N4125	
Q403	Type 2N4275	8210-1126	23342	2N4275	
Q404	Type 2N4275	8210-1126	23342	2N4275	
Q405	Type 2N4220	8210-1143	93916	2N4220	
Q406	Type 2N4220	8210-1143	93916	2N4220	
Q407	Type MPF103	8210-1157	04713	MPF-103	
Q408	Type 2N4125	8210-1125	93916	2N4125	
Q409	Type 2N4220	8210-1143	93916	2N4220	
Q410	Type 2N4220	8210-1143	93916	2N4220	
Q411	Type MPF103	8210-1157	04713	MPF-103	
Q412	Type 2N4125	8210-1125	93916	2N4125	
INTEGRATED CIRCUIT					
IC401	µA710C Linear	5432-7101	07263	U5B7710039X	

SIGNAL INDEX
DETECTOR-CIRCUIT ETCHED BOARD
(Reference Figures 7-7 and 7-8)

Signal	Description	Signal Type
ED90[1]	100 Hz, 90° Phase-Detector-Filter Ground	
ED90	90° Phase Detector Output	dc
GND	Signal Ground	
E90	90° Detector Input	dc and rms
−15 V	Power-Supply Voltage	dc
GND	Signal Ground	
IPR	0° Reference Voltage	rms
+15 V	Power-Supply Voltage	dc
EO	0° Detector Input	dc and rms
GND	Signal Ground	
EDO	0° Phase-Detector Output	dc
EDO[1]	100-Hz, 0° Phase-Detector-Filter Ground	

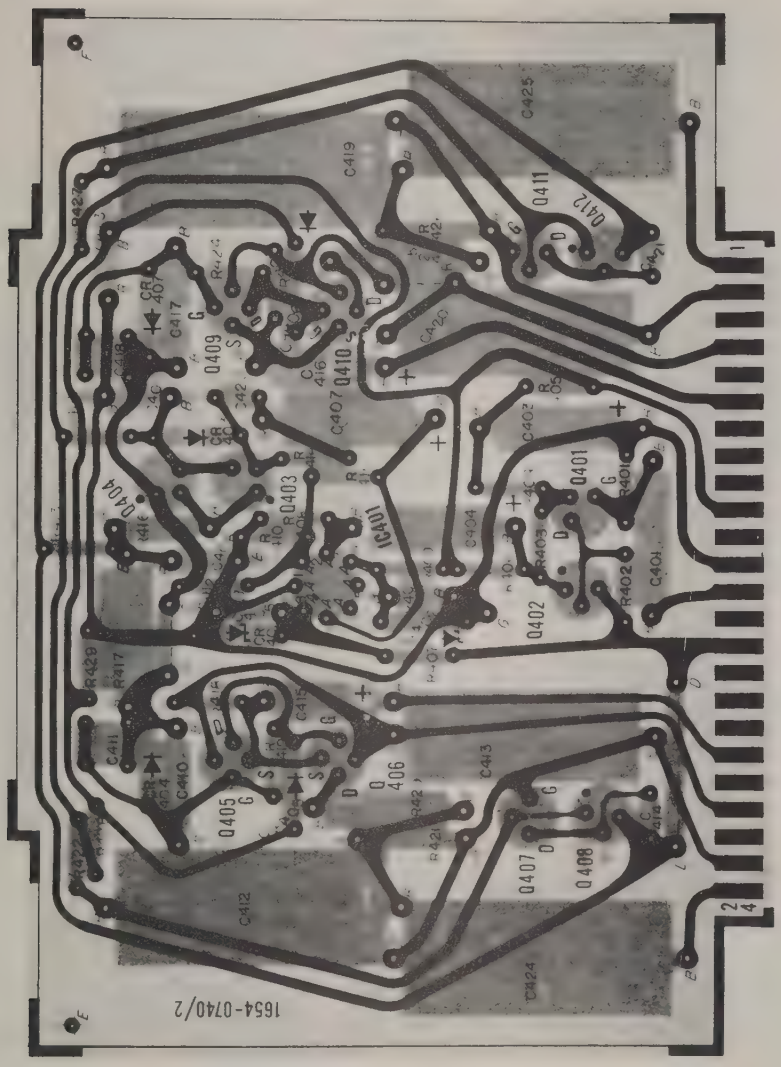
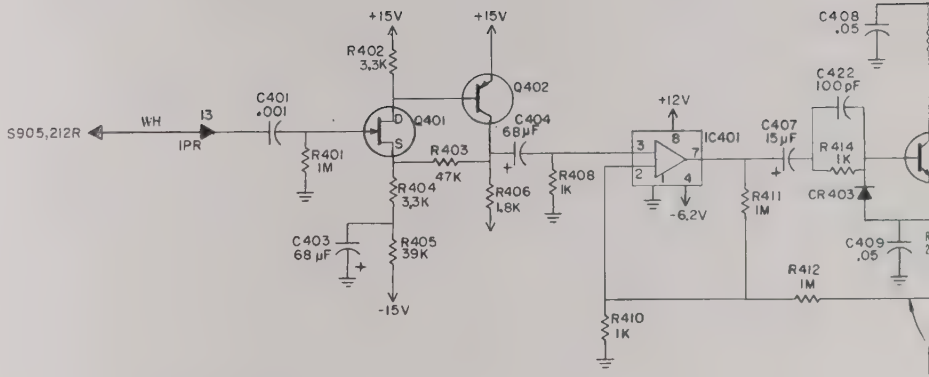


Figure 7-7. Detector-circuit etched-board assembly (P/N 1654-4741).

NOTE: The board is shown foil-side up. The number appearing on the foil side is *not* the part number. The dot on the foil at the transistor socket indicates the collector lead.



S905

IC 401

Q403, 404

Q402, 408, 412

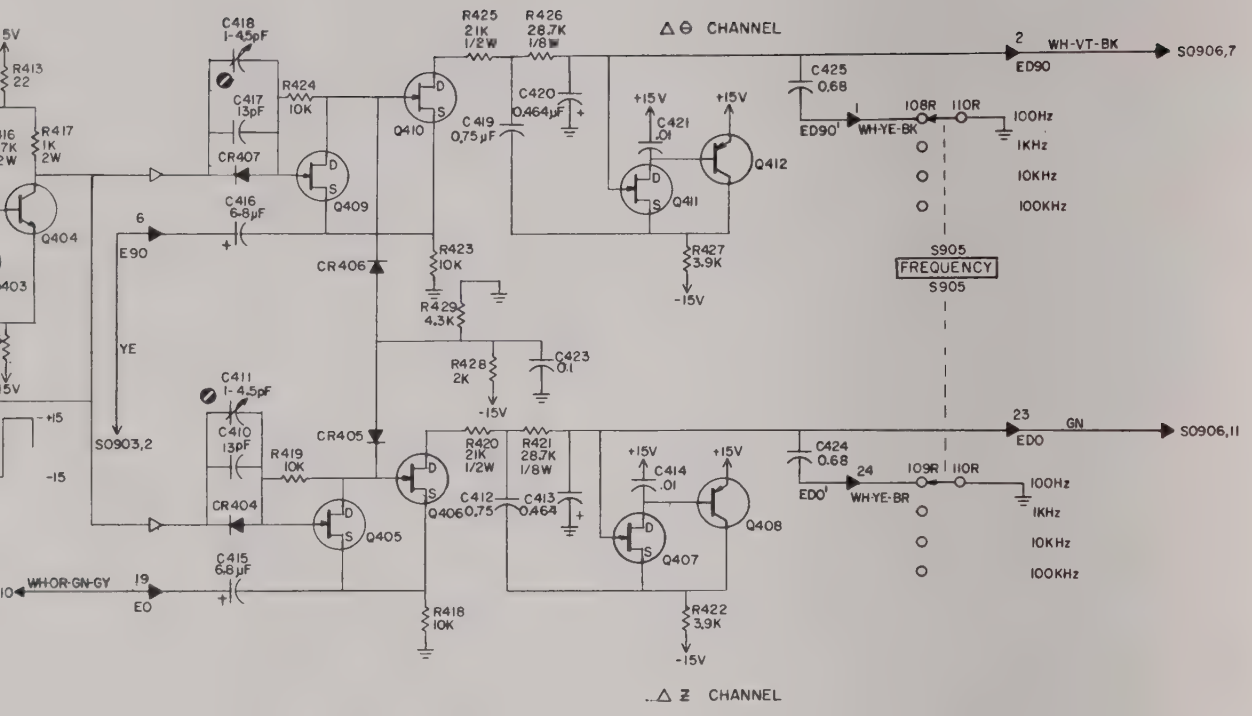
Q405,406
Q409,410

TRANSISTORS — BOTTOM VIEW

NOTE UNLESS SPECIFIED

~~1. POSITION OF ROTARY SWITCHES SHOWN COUNTERCLOCKWISE.~~

2. CONTACT NUMBERING OF SWITCHES EXPLAINED ON SEPARATE SHEET SUPPLIED IN INSTRUCTION BOOK.
3. REFER TO SERVICE NOTES IN INSTRUCTION BOOK FOR VOLTAGES APPEARING ON DIAGRAM
4. RESISTORS 1/4 WATT.
5. RESISTANCE IN OHMS K - 1000 OHMS M - 1 MEGOHM
6. CAPACITANCE VALUES ONE AND OVER IN PICOFARADS. LESS THAN ONE IN MICROFARADS.
7. ○ KNOB CONTROL
8. ● SCREWDRIVER CONTROL
9. AT - ANCHOR TERMINAL
10. TP - TEST POINT



SCHEMATIC DIAGRAM
FOR
DETECTORS
1654 IMPEDANCE COMPARATOR
(1654-4741)

Rotary switch sections are shown as viewed from the panel end of the shaft. The first digit of the contact number refers to the section. The section nearest the panel is 1, the next section back is 2, etc. The next two digits refer to the contact. Contact 01 is the first position clockwise from a strut screw (usually the screw above the locating key), and the other contacts are numbered sequentially (02, 03, 04, etc), proceeding clockwise around the section. A suffix F or R indicates that the contact is on the front or rear of the section, respectively.

Figure 7-8. Detector-circuit schematic diagram.

ELECTRICAL PARTS LIST

Ref. No.	Description	GR Part No.	Fed. Mfg. Code	Mfg. Part No.	Fed. Stock No.
CAPACITORS					
C501	Electrolytic 660 µF +150-10% 25 V	4450-6125	37942	TT, 660 µF	
C502	Electrolytic 660 µF +150-10% 25 V	4450-6125	37942	TT, 660 µF	
C503	Ceramic .01 µF +80-20% 500 V	4406-3109	72982	811 .01 µF +80-20%	5910-754-7049
C504	Electrolytic 60 µF +150-10% 25 V	4450-2900	56289	D17872	5910-799-9280
C505	Ceramic .01 µF +80-20% 500 V	4406-3109	72982	811 .01 µF +80-20%	5910-754-7049
C506	Electrolytic 33 µF +20% 10 V	4450-5400	56289	150D336X0010B1	5910-823-1623
C507	Electrolytic 60 µF +150-10% 25 V	4450-2900	56289	D17872	5910-799-9280
C901	Plastic 0.1 µF ±2% 100 V	4860-8251	84411	663 UW, .1 µF ±2% 100 V	
C902	Mica .01 µF ±2% 300 V	4780-0300	88419	CM35E .01 µF ±2%	
C903	Mica .001 µF ±2% 300 V	4690-4200	88419	CM20E, 1000 pF ±2%	5910-669-3241
C904	Mica .001 µF ±2% 300 V	4690-4200	88419	CM20E, 1000 pF ±2%	5910-669-3241
C905	Plastic .464 µF ±2% 100 V	4860-7990	84411	663 UW, .464 µF ±1% 100 V	
C906	Mica .003 µF ±2% 500 V	4750-0202	00656	1464, .003 µF ±2%	
C907	Mica 220 pF ±2% 500 V	4690-2700	00656	CM20E221G	5910-931-4153
C908	Plastic 1 µF ±10% 200 V	4860-8275	84411	663 UW, 1 µF ±10%	
C909	Mica 300 pF ±5% 300 V	4640-0770	72136	CM15, 300 pF ±5%	
C910	Mica .001 µF ±5% 300 V	4680-3200	81349	CM20D102J	5910-636-2134
CONNECTORS					
J901	Standard	0874-4504	24655	0874-4504	
J902	Unknown	0874-4504	24655	0874-4504	
J903	Standard	0874-4504	24655	0874-4504	
J904	Unknown	0874-4504	24655	0874-4504	
J905	Guard	4150-3200	24655	4150-3200	
J906	Ground	4150-3200	24655	4150-3200	
J907	Guard	4150-3200	24655	4150-3200	
J908	Start	4260-1030	82389	#111	
DIODES					
CR501	Type 1N3253	6081-1001	79089	IN3253	5961-814-4251
CR502	Type 1N3253	6081-1001	79089	IN3253	5961-814-4251
CR503	Type 1N3253	6081-1001	79089	IN3253	5961-814-4251
CR504	Type 1N3253	6081-1001	79089	IN3253	5961-814-4251
CR509	Type 1N4009	6082-1012	24446	IN4009	5961-892-8700
CR510	Type 1N4009	6082-1012	24446	IN4009	5961-892-8700
CR511	Type 1N4009	6082-1012	24446	IN4009	5961-892-8700
CR512	Type 1N4009	6082-1012	24446	IN4009	5961-892-8700
CR513	Type 1N4009	6082-1012	24446	IN4009	5961-892-8700
CR514	Type 1N957B	6083-1009	07910	IN957B	
RESISTORS					
R501	Low Power Wire Wound 2.7 Ω ±10% 2 W	6760-9279	75042	BWH, 2.7 Ω ±10%	5905-794-3857
R502	Low Power Wire Wound 4.7 Ω ±10% 2 W	6760-9479	75042	BWH, 4.7 Ω ±10%	5905-101-7586
R503	Composition 4.7 kΩ ±5% 1/4 W	6099-2475	75042	BTS, 4.7 kΩ ±5%	5905-686-9998
R504	Composition 10 Ω ±5% 1/4 W	6099-0105	75042	BTS, 10 Ω ±5%	5905-809-8596
R505	Low Power Wire Wound 2.7 Ω ±10% 2 W	6760-9279	75042	BWH, 2.7 Ω ±10%	5905-794-3857
R506	Composition 47 Ω ±5% 1/4 W	6099-0475	75042	BTS, 47 Ω ±5%	
R507	Film 5.11 kΩ ±1% 1/8 W	6250-1511	75042	CEA, 5.11 kΩ ±1%	5905-577-6734
R509	Composition 10 kΩ ±5% 1/4 W	6099-3105	75042	BTS, 10 kΩ ±5%	5905-683-2238
R510	Composition 10 kΩ ±5% 1/4 W	6099-3105	75042	BTS, 10 kΩ ±5%	5905-683-2238
R511	Composition 4.7 kΩ ±5% 1/4 W	6099-2475	75042	BTS, 4.7 kΩ ±5%	5905-686-9998
R512	Low Power Wire Wound 4.7 Ω ±10% 2 W	6760-9479	75042	BWH, 4.7 Ω ±10%	5905-101-3857
R513	Composition 10 Ω ±5% 1/4 W	6099-0105	75042	BTS, 10 Ω ±5%	5905-809-8596
R514	Composition 1.2 kΩ ±5% 1/4 W	6099-2125	75042	BTS, 1.2 kΩ ±5%	
R515	Composition 47 Ω ±5% 1/4 W	6099-0475	75042	BTS, 47 Ω ±5%	
R516	Composition 82 kΩ ±5% 1/4 W	6099-3825	75042	BTS, 82 kΩ ±5%	
R517	Composition 2.7 kΩ ±5% 1/4 W	6099-2275	75042	BTS, 2.7 kΩ ±5%	
R518	Composition 2.7 kΩ ±5% 1/4 W	6099-2275	75042	BTS, 2.7 kΩ ±5%	
R519	Pot. Wire Wound 1 kΩ ±10%	6056-0138	11236	115, 1 kΩ ±10%	
R520	Composition 3.3 kΩ ±5% 1/4 W	6099-2335	11236	BTS, 3.3 kΩ ±5%	5905-681-9969
R521	Composition 43 kΩ ±5% 1/4 W	6099-3435	11236	BTS, 43 kΩ ±5%	5905-549-9833
R522	Film 5.11 kΩ ±1% 1/8 W	6250-1511	11236	CEA, 5.11 kΩ ±1%	5905-577-6734
R523	Composition 4.7 kΩ ±5% 1/4 W	6099-2475	11236	BTS, 4.7 kΩ ±5%	5905-686-9998
R524	Low Power Wire Wound 100 Ω ±10% 2 W	6760-1109	11236	BWH, 100 Ω	5905-817-5635
R901	Film 2 kΩ ±1% 1/8 W	6250-1200	75042	CEA, 2 kΩ ±1%	5905-577-6614
R902	Pot. Comp. 2.5 kΩ ±10%	6000-0400	12697	53 MS, 2.5 kΩ ±10%	5905-776-0400
R903	Film 3.24 kΩ ±1/10% 1/8 W	6190-4050	75042	MEA-T2, 3.24 kΩ ±.1%	
R904	Film 12.4 kΩ ±1/10% 1/8 W	6190-6950	75042	MEA-T2, 12.4 kΩ ±.1%	
R905	Film 41.2 kΩ ±1/10% 1/8 W	6190-7750	75042	MEA-T2, 41.2 kΩ ±.1%	
R906	Film 133 kΩ ±1/10% 1/8 W	6190-9230	75042	MEA-T2, 133 kΩ ±.1%	
R907	Film 18.2 kΩ ±1% 1/8 W	6250-2182	75042	CEA, 18.2 kΩ ±1%	5905-686-3373
R908	Film 3.24 kΩ ±1/10% 1/8 W	6190-4050	75042	MEA-T2, 3.24 kΩ ±.1%	
R909	Film 12.4 kΩ ±1/10% 1/8 W	6190-6950	75042	MEA-T2, 12.4 kΩ ±.1%	
R910	Film 41.2 kΩ ±1/10% 1/8 W	6190-7750	75042	MEA-T2, 41.2 kΩ ±.1%	

Ref. No.	Description	GR Part No.	Fed. Mfg. Code	Mfg. Part No.	Fed. Stock No.
R911	Film 133 kΩ ±1/10% 1/8 W	6190-9230	75042	MEA-T2, 133 kΩ ±.1%	
R912	Film 18.2 kΩ ±1% 1/8 W	6250-2182	75042	CEA, 18.2 kΩ ±1%	5905-686-3373
R913	Pot. Wire Wound 10 kΩ ±10%	6056-0144	11236	115, 10 kΩ ±10%	
R914	Pot. Wire Wound 10 kΩ ±10%	6056-0144	11236	115, 10 kΩ ±10%	
R915	Pot. Wire Wound 200 Ω ±10%	6056-0134	11236	115, 200 Ω ±10%	
R916	Pot. Wire Wound 2 kΩ ±10%	6056-0140	11236	115, 2 kΩ ±10%	
R917	Pot. Wire Wound 2 kΩ ±10%	6056-0140	11236	115, 2 kΩ ±10%	
R918	Pot. Wire Wound 200 Ω ±10%	6056-0134	11236	115, 200 Ω ±10%	
R919	Film 215 Ω ±1% 1/2 W	6450-0215	75042	CEC, 215 Ω ±1%	
R920	Film 681 Ω ±1% 1/2 W	6450-0681	75042	CEC, 681 Ω ±1%	
R921	Film 215 Ω ±1% 1/2 W	6450-0215	75042	CEC, 215 Ω ±1%	
R922	Film 124 Ω ±1% 1/8 W	6250-0124	75042	CEA, 124 Ω ±1%	5905-815-4136
R923	Film 105 Ω ±1% 1/2 W	6450-0105	75042	CEC, 105 Ω ±1%	
R924	Film 12.4 kΩ ±0.1% 1/8 W	6190-6950	75042	MEA-T2, 12.4 kΩ ±.1%	
R925	Precision Wire Wound 62.31 Ω ±0.1% 1/8 W	6981-2004	24655	6981-2004	
R926	Film 105 Ω ±1% 1/2 W	6450-0105	75042	CEC, 105 Ω ±1%	
R927	Film 124 Ω ±1% 1/8 W	6250-0124	75042	CEA, 124 Ω ±1%	5905-815-4136
R928	Film 215 Ω ±1% 1/2 W	6450-0215	75042	CEC, 215 Ω ±1%	
R929	Film 681 Ω ±1% 1/2 W	6450-0681	75042	CEC, 681 Ω ±1%	
R930	Film 215 Ω ±1% 1/2 W	6450-0215	75042	CEC, 215 Ω ±1%	
R931	Pot. Wire Wound 2 kΩ ±10%	6056-0140	11236	115, 2 kΩ ±10%	
R932	Pot. Wire Wound 2 kΩ ±10%	6056-0140	11236	115, 2 kΩ ±10%	
R933	Composition 820 Ω ±5% 1/4 W	6099-1825	75042	BTS, 820 Ω ±5%	
R934	Composition 12 kΩ ±5% 1/4 W	6099-3125	75042	BTS, 12 kΩ ±5%	
R935	Composition 1 kΩ ±10% 1 W	6110-2109	01121	GB, 1 kΩ ±10%	
R936	Composition 200 Ω ±5% 1/4 W	6099-1205	75042	BTS, 200 Ω ±5%	5905-892-0107
R937	Composition 200 Ω ±5% 1/4 W	6099-1205	75042	BTS, 200 Ω ±5%	5905-892-0107
R938*	Composition 1 kΩ ±5% 1/4 W	6099-2105	75042	BTS, 1 kΩ ±5%	5905-681-6462
R939*	Composition 1 kΩ ±5% 1/4 W	6099-2105	75042	BTS, 1 kΩ ±5%	5905-681-6462
R940	Composition 3.9 k ±5% 1/4 W	6099-2395	75042	BTS, 3.9 k ±5%	
SO901	Connector, Multiple Socket	4230-2724	95354	91-6024-1201-00	5935-688-9925
SO903	Connector, Multiple Socket	4230-2724	95354	91-6024-1201-00	5935-688-9925
SO904	Connector, Multiple Socket	4230-2724	95354	91-6024-1201-00	5935-688-9925
SO906	Connector, Multiple Socket	4230-2724	95354	91-6024-1201-00	5935-688-9925
SO907	Connector, Multiple Socket	4230-2724	95354	91-6024-1201-00	
SO909	Connector, Multiple Socket	4230-5406	02660	126-198	
SO910	Connector, Multiple Socket	4230-5405	02660	126-218	
SWITCHES					
S501	Power OFF, Toggle	7910-1300	04009	83053-SA	5930-909-3510
S502	Line Voltage Selector	7910-0831	42190	4603	
S901	Full Scale, Thousands/Hundreds	7890-5200	76854	270954-F2	
S902	Test Voltage	7890-5210	76854	270955-F5	
S903	Full Scale, Tenths	7890-5200	76854	270954-F2	
S904	Measurement Selector	7890-5220	76854	270953-F1C	
S905	Frequency Selector	7890-5230	76854	270956-F5	
S906	Input Selector	7890-5240	76854	270952-F2	
S907	Start, Ext./Self	7910-0774	76854	#78	
S908	Magnitude Linearizer, In/Out	7910-0831	42190	4603	
TRANSISTORS					
Q501	Type 2N3740	8210-1121	93916	2N3740	
Q502	Type 2N3906	8210-1112	93916	2N3906	
Q503	Type 2N3414	8210-1047	24446	2N3416	5961-989-2749
Q504	Type 2N3414	8210-1047	24446	2N3416	5961-989-2749
Q505	Type 40250	8210-1095	12672	40250	
Q506	Type 2N3900	8210-1118	93916	2N3900	
Q507	Type 2N3638	8210-1096	07263	2N3638	5961-912-9008
Q508	Type 2N3905	8210-1114	04713	2N3905	
MISCELLANEOUS					
F501	Slo-Blo	5330-0500	71400	MDL, 0.15 Amp	
F502	Slo-Blo	5330-0400	71400	MDL, .1 Amp	5920-356-2185
P501	Pilot Light	5600-0316	71744	#345	
P901	Pilot Light	5600-0316	71744	#345	
M901		5730-1414	91929	ME-6	
M902		5730-1415	91929	ME-6	
T501	Power	0345-4026	24655	0345-4026	
T901	Power	0745-4470	24655	0745-4470	
T902	Transformer Asm.	1654-2000	24655	1654-2000	
PL501	Power	4240-0600	24655	4240-0600	5935-816-0254

*FACTORY ADJUSTED

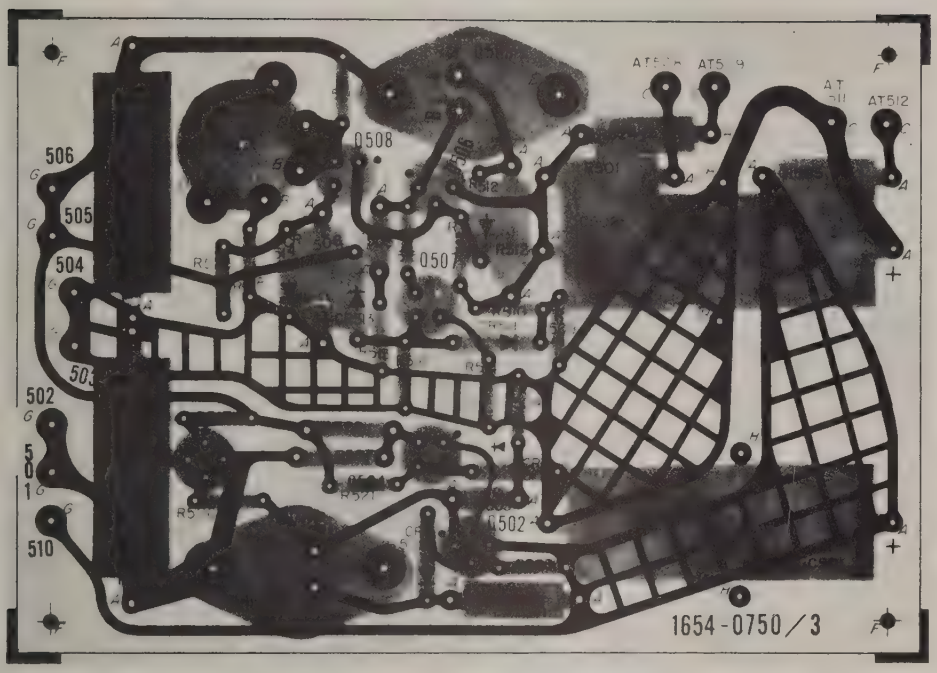
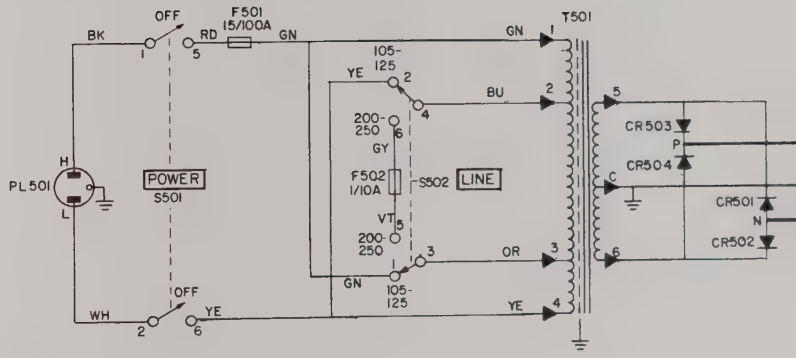


Figure 7-9. Power-supply etched-board assembly (P/N 1654-2751).

NOTE: The board is shown foil-side up. The number appearing on the foil side is *not* the part number. The dot on the foil at the transistor socket indicates the collector lead.

TRANSFORMER-RECTIFIER CIRCUIT VA

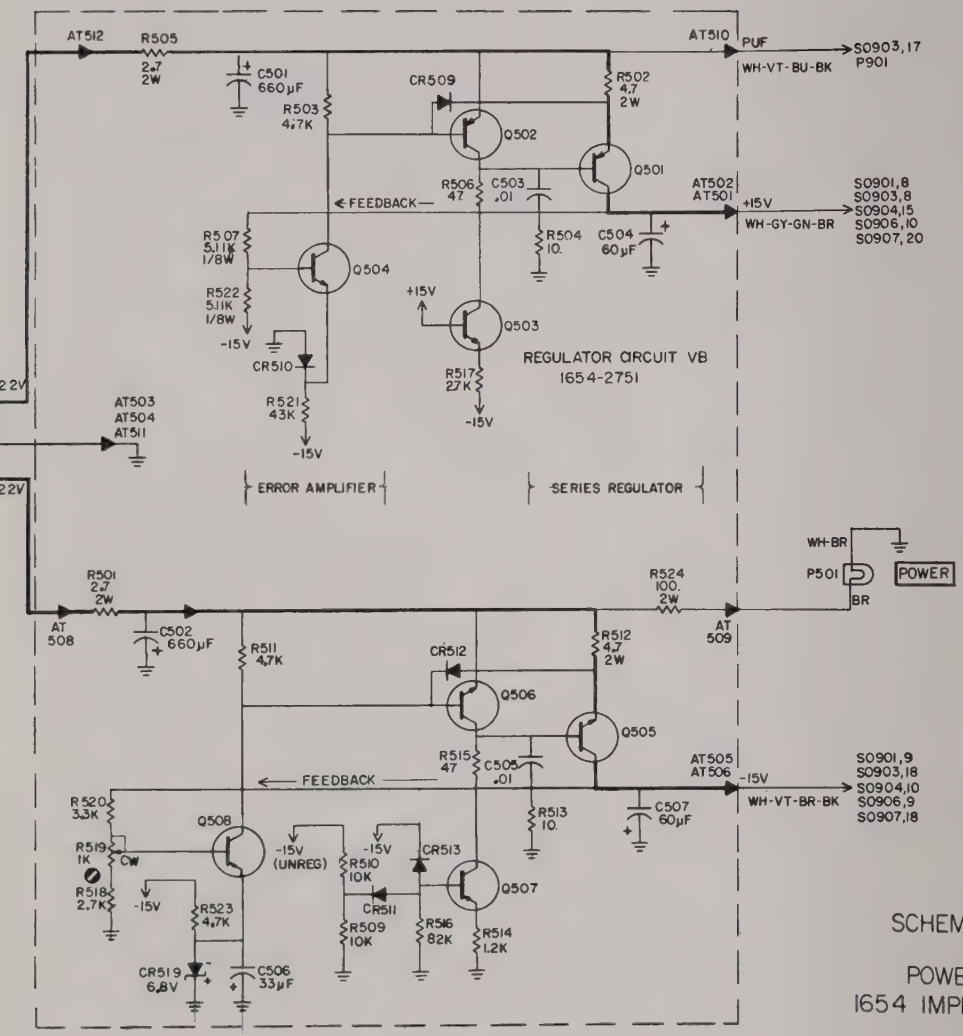


Q503, 504, 506 Q501, 505 Q507

TRANSISTORS - BOTTOM VIEW

NOTE UNLESS SPECIFIED

1. ~~POSITION OF ROTARY SWITCHES SHOWN COUNTERCLOCKWISE.~~
2. CONTACT NUMBERING OF SWITCHES EXPLAINED ON SEPARATE SHEET SUPPLIED IN INSTRUCTION BOOK.
3. REFER TO SERVICE NOTES IN INSTRUCTION BOOK FOR VOLTAGES APPEARING ON DIAGRAM.
4. RESISTORS 1/4 WATT.
5. RESISTANCE IN OHMS K - 1000 OHMS M - 1 MEGOHM
6. CAPACITANCE VALUES ONE AND OVER IN PICOFARADS, LESS THAN ONE IN MICROFARADS.
7. ◯ KNOB CONTROL
8. ⊘ SCREWDRIVER CONTROL
9. AT - ANCHOR TERMINAL
10. TP - TEST POINT



SCHEMATIC DIAGRAM
FOR
POWER SUPPLY
1654 IMPEDANCE COMPARATOR

Q502,508

Figure 7-10. Power-supply schematic diagram.

ELECTRICAL PARTS LIST

Ref. No.	Description	GR Part No.	Fed. Mfg. Code	Mfg. Part No.	Fed. Stock No.
CAPACITORS					
C601	Plastic 0.1 µF ±10% 100 V	4860-8250	84411	663 UW, .1 µF ±10%	
C602	Ceramic .01 µF +80-20% 500 V	4406-3109	72982	811, .01 µF +80-20%	5910-754-7049
C603	Ceramic .001 µF +80-20% 500 V	4404-2109	72982	831, .001µF +80-20%	5910-983-9994
C605	Plastic 0.1 µF ±10% 100 V	4860-8250	84411	663 UW, .1 µF ±10%	
C606	Ceramic .01 µF +80-20% 500 V	4406-3109	72982	811, .01 µF +80-20%	5910-754-7049
C607	Ceramic .001 µF +80-20% 500 V	4404-2109	72982	831, .001 µF +80-20%	5910-983-9994
DIODES					
CR601	Type 1N459A	6082-1011	07910	IN459A	5961-815-8451
CR602	Type 1N459A	6082-1011	07910	IN459A	5961-815-8451
CR603	Type 1N459A	6082-1011	07910	IN459A	5961-815-8451
CR604	Type 1N459A	6082-1011	07910	IN459A	5961-815-8451
CR605	Type 1N459A	6082-1011	07910	IN459A	5961-815-8451
CR606	Type 1N4009	6082-1012	24446	IN4009	5961-892-8700
CR607	Type 1N4009	6082-1012	24446	IN4009	5961-892-8700
CR608	Type 1N4009	6082-1012	24446	IN4009	5961-892-8700
CR609	Type 1N4009	6082-1012	24446	IN4009	5961-892-8700
CR610	Type 1N4009	6082-1012	24446	IN4009	5961-892-8700
INTEGRATED CIRCUITS					
IC601	Linear	5432-7091	07263	UA-709C	
IC602	Linear	5432-7091	07263	UA-709C	
RESISTORS					
R601	Mica 1.5 kΩ ±10%	6740-1603	02606	JB31J7	
R602	Composition 20 kΩ ±5% 1/4 W	6099-3205	75042	BTS, 20 kΩ ±5%	5905-686-3368
R603	Composition 20 kΩ ±5% 1/4 W	6099-3205	75042	BTS, 20 kΩ ±5%	5905-686-3368
R604*	Composition 1.5 mΩ ±5% 1/2 W	6100-5155	01121	RC20GF155J	5905-279-1754
R605	Film 49.9 Ω ±1% 1/8 W	6250-9499	75042	CEA, 49.9 Ω ±1%	5905-800-7815
R606*	Composition 820 kΩ ±5% 1/4 W	6099-4825	75042	BTS, 820 kΩ ±5%	
R607	Film 698 Ω ±1% 1/8 W	6250-0698	75042	CEA, 698 Ω ±1%	5905-824-8535
R608	Composition 390 kΩ ±5% 1/4 W	6099-4395	75042	BTS, 390 kΩ ±5%	
R609	Film 10 kΩ ±1% 1/8 W	6250-2100	75042	CEA, 10 kΩ ±1%	5905-883-4847
R610	Composition 4.3 mΩ ±5% 1/4 W	6099-5435	75042	BTS, 4.3 mΩ ±5%	
R611	Composition 2.7 kΩ ±5% 1/4 W	6099-2275	75042	BTS, 2.7 kΩ ±5%	
R612	Composition 4.7 kΩ ±5% 1/4 W	6099-2475	75042	BTS, 4.7 kΩ ±5%	5905-686-9998
R613	Film 49.9 Ω ±1% 1/8 W	6250-9499	75042	CEA, 49.9 Ω ±1%	5905-800-7815
R614	Film 37.4 Ω ±1% 1/8 W	6250-9374	75042	CEA, 37.4 Ω ±1%	5905-878-2676
R615*	Composition 10 kΩ ±5% 1/4 W	6099-3105	75042	BTS, 10 kΩ ±5%	5905-683-2238
R616	Film 6.49 kΩ ±1% 1/8 W	6250-1649	75042	CEA, 6.49 kΩ ±1%	5905-833-8744
R617	Film 60.4 kΩ ±1% 1/8 W	6250-2604	75042	CEA, 60.4 kΩ ±1%	5905-755-0675
R618	Film 1 kΩ ±.1% 1/8 W	6190-2330	75042	MEA-T2, 1 kΩ ±.1%	
R619	Composition 1.5 kΩ ±10% 1/4 W	6099-2159	75042	BTS, 1.5 kΩ ±10%	
R620	Composition 20 kΩ ±5% 1/4 W	6099-3205	75042	BTS, 20 kΩ ±5%	5905-686-3368
R621	Composition 20 kΩ ±5% 1/4 W	6099-3205	75042	BTS, 20 kΩ ±5%	5905-686-3368
R622	Composition 270 Ω ±10% 1 W	6110-1279	01121	GB, 270 Ω ±10%	
R623	Composition 270 Ω ±10% 1 W	6110-1279	01121	GB, 270 Ω ±10%	
R624	Composition 2.2 kΩ ±10% 1/4 W	6099-2229	75042	BTS, 2.2 kΩ ±10%	
R625	Film 6.81 kΩ ±.1% 1/8 W	6190-5120	75042	MEA-T2, 6.81 kΩ ±.1%	
R626	Film 3.16 kΩ ±.1% 1/8 W	6190-4000	75042	MEA-T2, 3.16 kΩ ±.1%	
R628	Composition 4.3 mΩ ±5% 1/4 W	6099-5435	75042	BTS, 4.3 mΩ ±5%	
R629	Film 60.4 kΩ ±1% 1/8 W	6250-2604	75042	CEA, 60.4 kΩ ±1%	5905-755-0675
R630	Film 1 kΩ ±.1% 1/8 W	6190-2330	75042	MEA-T2, 1 kΩ ±.1%	
R631	Composition 1.5 kΩ ±10% 1/4 W	6099-2159	75042	BTS, 1.5 kΩ ±10%	
R632	Composition 20 kΩ ±5% 1/4 W	6099-3205	75042	BTS, 20 kΩ ±5%	5905-686-3368
R633	Composition 20 kΩ ±5% 1/4 W	6099-3205	75042	BTS, 20 kΩ ±5%	5905-686-3368
R634	Composition 270 Ω ±10% 1 W	6110-1279	01121	GB, 270 Ω ±10%	
R635	Composition 270 Ω ±10% 1 W	6110-1279	01121	GB, 270 Ω ±10%	
R636	Composition 2.2 kΩ ±10% 1/4 W	6099-2229	75042	BTS, 2.2 kΩ ±10%	
R637	Film 6.81 kΩ ±.1% 1/8 W	6190-5120	75042	MEA-T2, 6.81 ±.1%	
R638	Film 3.16 kΩ ±.1% 1/8 W	6190-4000	75042	MEA-T2, 3.16 kΩ ±.1%	
Q601	Type 2N3414	8210-1047	24446	2N3416	5961-989-2749
Q602	Type 2N4125	8210-1125	93916	2N4125	
Q603	Type 2N3414	8210-1047	24446	2N3416	5961-989-2749
Q604	Type 2N4125	8210-1125	93916	2N4125	

*SELECTED BY LAB.

Ref. No.	Description	GR Part No.	Fed. Mfg. Code	Mfg. Part No.	Fed. Stock No.
R911	Film 133 kΩ ±1/10% 1/8 W	6190-9230	75042	MEA-T2, 133 kΩ ±.1%	
R912	Film 18.2 kΩ ±1% 1/8 W	6250-2182	75042	CEA, 18.2 kΩ ±1%	5905-686-3373
R913	Pot. Wire Wound 10 kΩ ±10%	6056-0144	11236	115, 10 kΩ ±10%	
R914	Pot. Wire Wound 10 kΩ ±10%	6056-0144	11236	115, 10 kΩ ±10%	
R915	Pot. Wire Wound 200 Ω ±10%	6056-0134	11236	115, 200 Ω ±10%	
R916	Pot. Wire Wound 2 kΩ ±10%	6056-0140	11236	115, 2 kΩ ±10%	
R917	Pot. Wire Wound 2 kΩ ±10%	6056-0140	11236	115, 2 kΩ ±10%	
R918	Pot. Wire Wound 200 Ω ±10%	6056-0134	11236	115, 200 Ω ±10%	
R919	Film 215 Ω ±1% 1/2 W	6450-0215	75042	CEC, 215 Ω ±1%	
R920	Film 681 Ω ±1% 1/2 W	6450-0681	75042	CEC, 681 Ω ±1%	
R921	Film 215 Ω ±1% 1/2 W	6450-0215	75042	CEC, 215 Ω ±1%	
R922	Film 124 Ω ±1% 1/8 W	6250-0124	75042	CEA, 124 Ω ±1%	5905-815-4136
R923	Film 105 Ω ±1% 1/2 W	6450-0105	75042	CEC, 105 Ω ±1%	
R924	Film 12.4 kΩ ±0.1% 1/8 W	6190-6950	75042	MEA-T2, 12.4 kΩ ±.1%	
R925	Precision Wire Wound 62.31 Ω ±0.1% 1/8 W	6981-2004	24655	6981-2004	
R926	Film 105 Ω ±1% 1/2 W	6450-0105	75042	CEC, 105 Ω ±1%	
R927	Film 124 Ω ±1% 1/8 W	6250-0124	75042	CEA, 124 Ω ±1%	5905-815-4136
R928	Film 215 Ω ±1% 1/2 W	6450-0215	75042	CEC, 215 Ω ±1%	
R929	Film 681 Ω ±1% 1/2 W	6450-0681	75042	CEC, 681 Ω ±1%	
R930	Film 215 Ω ±1% 1/2 W	6450-0215	75042	CEC, 215 Ω ±1%	
R931	Pot. Wire Wound 2 kΩ ±10%	6056-0140	11236	115, 2 kΩ ±10%	
R932	Pot. Wire Wound 2 kΩ ±10%	6056-0140	11236	115, 2 kΩ ±10%	
R933	Composition 820 Ω ±5% 1/4 W	6099-1825	75042	BTS, 820 Ω ±5%	
R934	Composition 12 kΩ ±5% 1/4 W	6099-3125	75042	BTS, 12 kΩ ±5%	
R935	Composition 1 kΩ ±10% 1 W	6110-2109	01121	GB, 1 kΩ ±10%	
R936	Composition 200 Ω ±5% 1/4 W	6099-1205	75042	BTS, 200 Ω ±5%	5905-892-0107
R937	Composition 200 Ω ±5% 1/4 W	6099-1205	75042	BTS, 200 Ω ±5%	5905-892-0107
R938*	Composition 1 kΩ ±5% 1/4 W	6099-2105	75042	BTS, 1 kΩ ±5%	5905-681-6462
R939*	Composition 1 kΩ ±5% 1/4 W	6099-2105	75042	BTS, 1 kΩ ±5%	5905-681-6462
R940	Composition 3.9 k ±5% 1/4 W	6099-2395	75042	BTS, 3.9 k ±5%	
SO901	Connector, Multiple Socket	4230-2724	95354	91-6024-1201-00	5935-688-9925
SO903	Connector, Multiple Socket	4230-2724	95354	91-6024-1201-00	5935-688-9925
SO904	Connector, Multiple Socket	4230-2724	95354	91-6024-1201-00	5935-688-9925
SO906	Connector, Multiple Socket	4230-2724	95354	91-6024-1201-00	5935-688-9925
SO907	Connector, Multiple Socket	4230-2724	95354	91-6024-1201-00	
SO909	Connector, Multiple Socket	4230-5406	02660	126-198	
SO910	Connector, Multiple Socket	4230-5405	02660	126-218	
SWITCHES					
S501	Power OFF, Toggle	7910-1300	04009	83053-SA	5930-909-3510
S502	Line Voltage Selector	7910-0831	42190	4603	
S901	Full Scale, Thousands/Hundreds	7890-5200	76854	270954-F2	
S902	Test Voltage	7890-5210	76854	270955-F5	
S903	Full Scale, Tenths	7890-5200	76854	270954-F2	
S904	Measurement Selector	7890-5220	76854	270953-F1C	
S905	Frequency Selector	7890-5230	76854	270956-F5	
S906	Input Selector	7890-5240	76854	270952-F2	
S907	Start, Ext./Self	7910-0774	76854	#78	
S908	Magnitude Linearizer, In/Out	7910-0831	42190	4603	
TRANSISTORS					
Q501	Type 2N3740	8210-1121	93916	2N3740	
Q502	Type 2N3906	8210-1112	93916	2N3906	
Q503	Type 2N3414	8210-1047	24446	2N3416	5961-989-2749
Q504	Type 2N3414	8210-1047	24446	2N3416	5961-989-2749
Q505	Type 40250	8210-1095	12672	40250	
Q506	Type 2N3900	8210-1118	93916	2N3900	
Q507	Type 2N3638	8210-1096	07263	2N3638	5961-912-9008
Q508	Type 2N3905	8210-1114	04713	2N3905	
MISCELLANEOUS					
F501	Slo-Blo	5330-0500	71400	MDL, 0.15 Amp	
F502	Slo-Blo	5330-0400	71400	MDL, .1 Amp	5920-356-2185
P501	Pilot Light	5600-0316	71744	#345	
P901	Pilot Light	5600-0316	71744	#345	
M901		5730-1414	91929	ME-6	
M902		5730-1415	91929	ME-6	
T501	Power	0345-4026	24655	0345-4026	
T901	Power	0745-4470	24655	0745-4470	
T902	Transformer Asm.	1654-2000	24655	1654-2000	
PL501	Power	4240-0600	24655	4240-0600	5935-816-0254

*FACTORY ADJUSTED

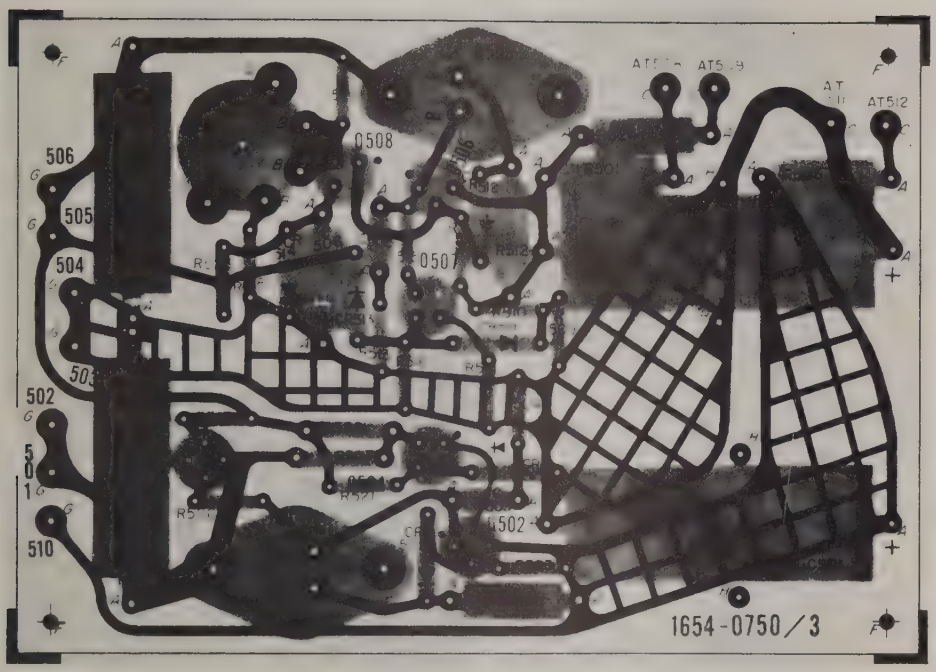
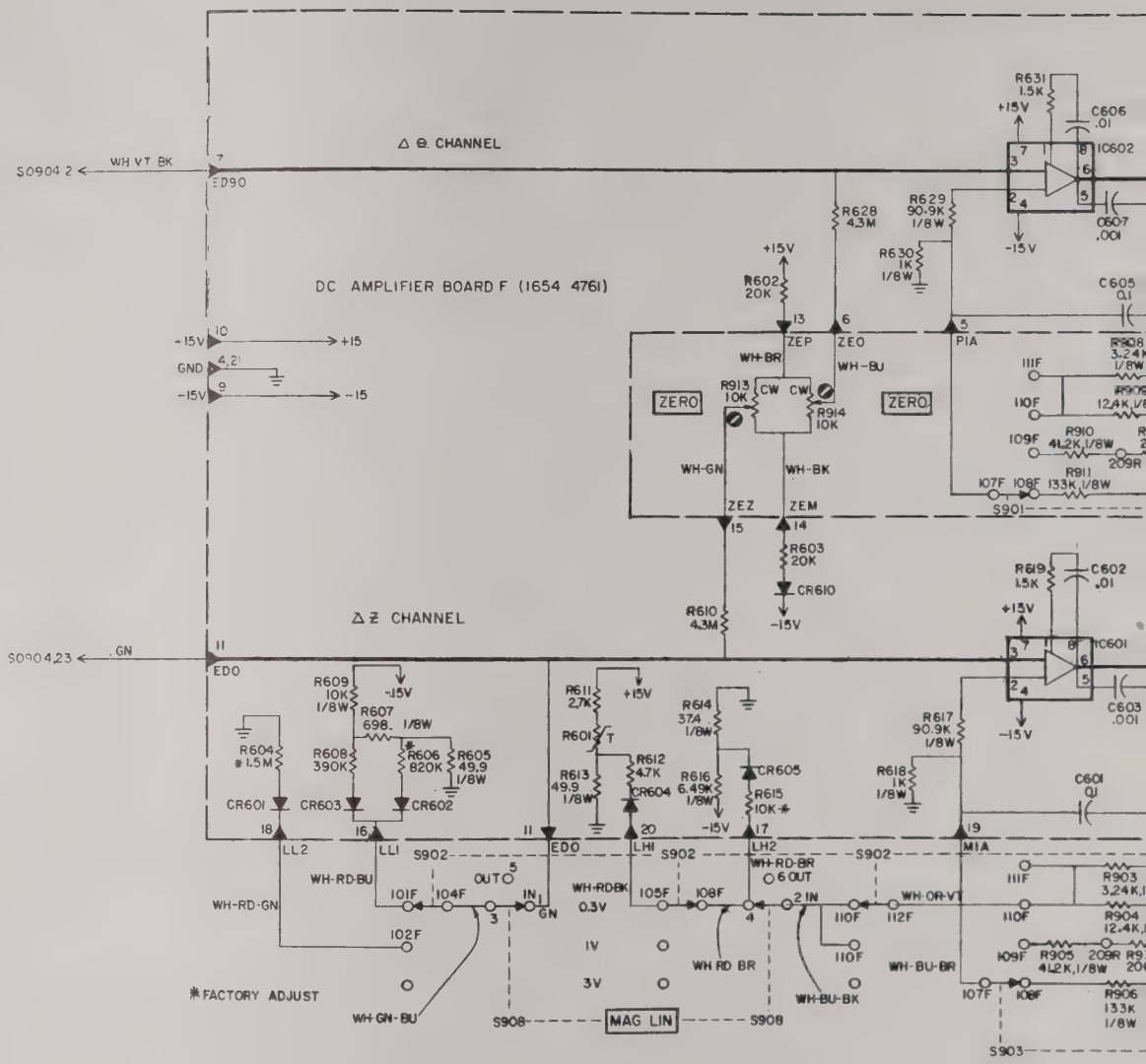


Figure 7-9. Power-supply etched-board assembly (P/N 1654-?751).

NOTE: The board is shown foil-side up. The number appearing on the foil side is *not* the part number. The dot on the foil at the transistor socket indicates the collector lead.

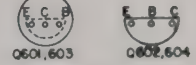


S901 & S903

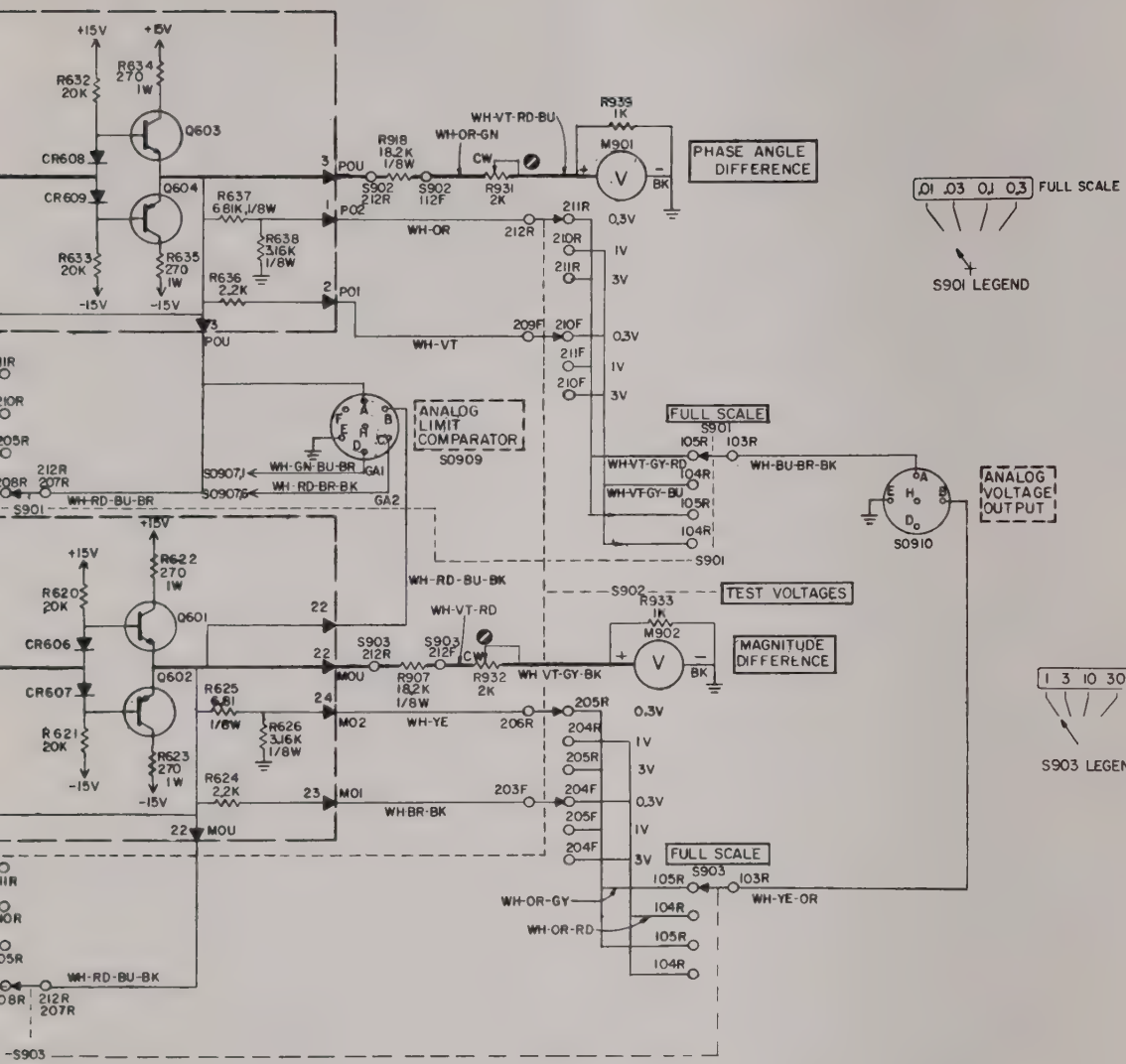
S902

NOTE UNLESS SPECIFIED

1. ~~POSITION OF ROTARY SWITCHES SHOWN COUNTERCLOCKWISE.~~
2. CONTACT NUMBERING OF SWITCHES EXPLAINED ON SEPARATE SHEET SUPPLIED IN INSTRUCTION BOOK.
3. REFER TO SERVICE NOTES IN INSTRUCTION BOOK FOR VOLTAGES APPEARING ON DIAGRAM.
4. RESISTORS 1/2 WATT.
5. RESISTANCE IN OHMS K - 1000 OHMS M - 1 MEGOHM
6. CAPACITANCE VALUES ONE AND OVER IN MICROFARADS. LESS THAN ONE IN MICROFARADS.
7. ○ KNOB CONTROL
8. ● SCREWDRIVER CONTROL
9. AT - ANCHOR TERMINAL
10. TP - TEST POINT



TRANSISTORS
BOTTOM VIEW



SCHEMATIC DIAGRAM
FOR
DC AMPLIFIERS
1654 IMPEDANCE COMPARATOR

Rotary switch sections are shown as viewed from the panel end of the shaft. The first digit of the contact number refers to the section. The section nearest the panel is 1, the next section back is 2, etc. The next two digits refer to the contact. Contact 01 is the first position clockwise from a strut screw (usually the screw above the locating key), and the other contacts are numbered sequentially (02, 03, 04, etc), proceeding clockwise around the section. A suffix F or R indicates that the contact is on the front or rear of the section, respectively.

Figure 7-12. DC amplifier circuit schematic diagram.

ELECTRICAL PARTS LIST

Ref. No.	Description	GR Part No.	Fed. Mfg. Code	Mfg. Part No.	Fed. Stock No.
CAPACITORS					
C701	Ceramic 0.47 µF +80-20% 10 V	4428-4479	56289	41C172	
C702	Ceramic 0.47 µF +80-20% 10 V	4428-4479	56289	41C172	
C703	Electrolytic 3.3 µF ±20% 15 V	4450-4600	56289	150D335X0015A2	5910-837-9325
C704	Electrolytic 15 µF +150-10% 15 V	4450-3700	37942	TT, 15 µF 15 V	
DIODES					
CR701	Type 1N4009	6082-1012	24446	IN4009	5961-892-8700
CR702	Type 1N4009	6082-1012	24446	IN4009	5961-892-8700
CR703	Type 1N191	6082-1008	93916	IN191	5961-296-3360
CR704	Type 1N4009	6082-1012	24446	IN4009	5961-892-8700
CR705	Type 1N191	6082-1008	93916	IN191	5961-296-3360
CR706	Type 1N4009	6082-1012	24446	IN4009	5961-892-8700
CR707	Type 1N4009	6082-1012	24446	IN4009	5961-892-8700
RESISTORS					
R701	Composition 10 kΩ ±10% 1/4 W	6099-3109	75042	BTS, 10 kΩ ±10%	
R702	Composition 220 kΩ ±5% 1/4 W	6099-4225	75042	BTS, 220 kΩ ±5%	
R703	Composition 20 kΩ ±5% 1/4 W	6099-3205	75042	BTS, 20 kΩ ±5%	5905-686-3368
R704	Composition 3.3 kΩ ±10% 1/4 W	6099-2339	75042	BTS, 3.3 kΩ ±10%	
R705	Composition 270 Ω ±10% 1/4 W	6099-1279	75042	BTS, 270 Ω ±10%	
R706	Composition 100 kΩ ±10% 1/4 W	6099-4109	75042	BTS, 100 kΩ ±10%	
R707	Composition 1 mΩ ±10% 1/4 W	6099-5109	75042	BTS, 1 mΩ ±10%	
R708	Composition 20 kΩ ±5% 1/4 W	6099-3205	75042	BTS, 20 kΩ ±5%	5905-686-3368
R709	Composition 3.3 kΩ ±10% 1/4 W	6099-2339	75042	BTS, 3.3 kΩ ±10%	
R710	Composition 100 kΩ ±10% 1/4 W	6099-4109	75042	BTS, 100 kΩ ±10%	
R711	Composition 1 kΩ ±5% 1/4 W	6099-2105	75042	BTS, 1 kΩ ±5%	5905-681-6462
R712	Composition 10 kΩ ±10% 1/4 W	6099-3109	75042	BTS, 10 kΩ ±10%	
R713	Composition 56 kΩ ±5% 1/4 W	6099-3565	75042	BTS, 56 kΩ ±5%	5905-800-0179
R714	Composition 270 Ω ±5% 1/4 W	6099-1275	75042	BTS, 270 Ω ±10%	
R715	Composition 27 kΩ ±10% 1/4 W	6099-3279	75042	BTS, 27 kΩ ±10%	
R716	Composition 27 kΩ ±10% 1/4 W	6099-3279	75042	BTS, 27 kΩ ±10%	
R717	Composition 10 kΩ ±10% 1/4 W	6099-3109	75042	BTS, 10 kΩ ±10%	
R718	Composition 4.7 kΩ ±10% 1/4 W	6099-2479	75042	BTS, 4.7 kΩ ±10%	
R719	Composition 91 kΩ ±5% 1/4 W	6099-3915	75042	BTS, 91 kΩ ±5%	
R720	Composition 4.7 kΩ ±10% 1/4 W	6099-2479	75042	BTS, 4.7 kΩ ±10%	
R721	Composition 4.7 kΩ ±10% 1/4 W	6099-2479	75042	BTS, 4.7 kΩ ±10%	
R722	Composition 10 kΩ ±10% 1/4 W	6099-3109	75042	BTS, 10 kΩ ±10%	
R723	Low Power, Wire Wound 120 Ω ±10% 2 W	6760-1129	75042	BWH, 120 Ω ±10%	
R724	Composition 4.7 kΩ ±10% 1/4 W	6099-2479	75042	BTS, 4.7 kΩ ±10%	
R725	Composition 39 kΩ ±10% 1/4 W	6099-3399	75042	BTS, 39 kΩ ±10%	
R726	Composition 10 kΩ ±10% 1/4 W	6099-3109	75042	BTS, 10 kΩ ±10%	
TRANSISTORS					
Q701	Type 2N3414	8210-1047	24446	2N3416	5961-989-2749
Q702	Type 2N3414	8210-1047	24446	2N3416	5961-989-2749
Q703	Type 2N3414	8210-1047	24446	2N3416	5961-989-2749
Q704	Type 2N4125	8210-1125	93916	2N4125	
Q705	Type 2N3414	8210-1047	24446	2N3416	5961-989-2749
Q706	Type 2N4125	8210-1125	93916	2N4125	
Q707	Type 2N3414	8210-1047	24446	2N3416	5961-989-2749
Q708	Type 2N3414	8210-1047	24446	2N3416	5961-989-2749
Q709	Type 2N3414	8210-1047	24446	2N3416	5961-989-2749

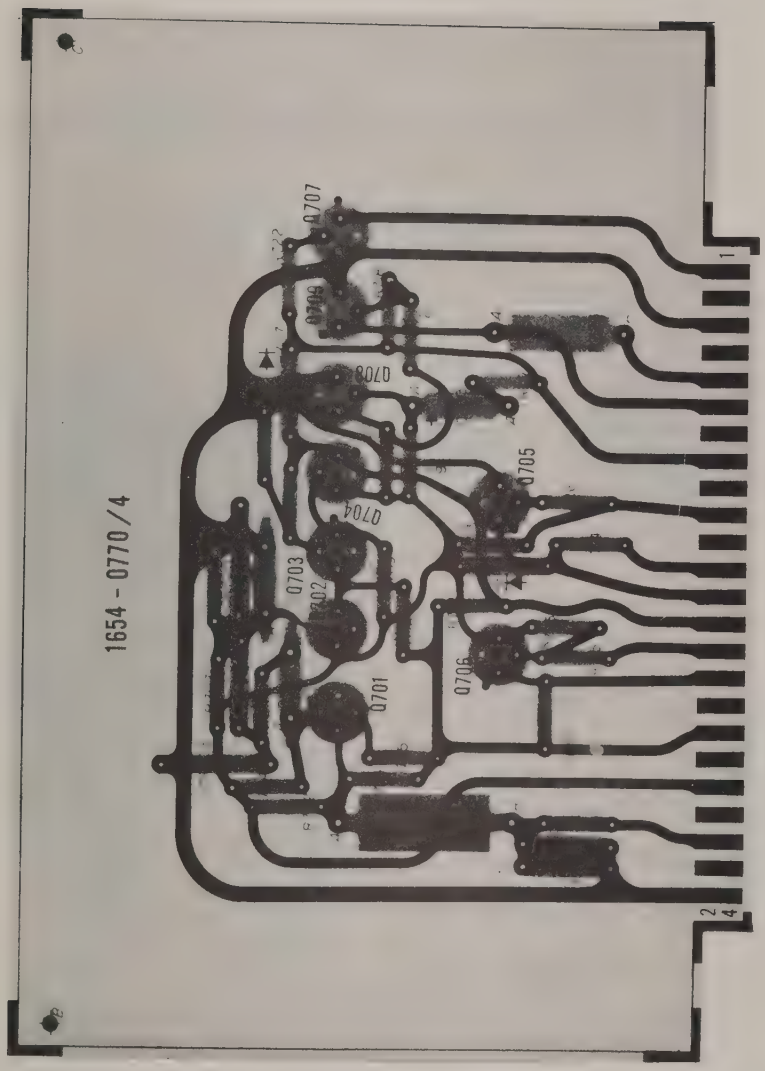
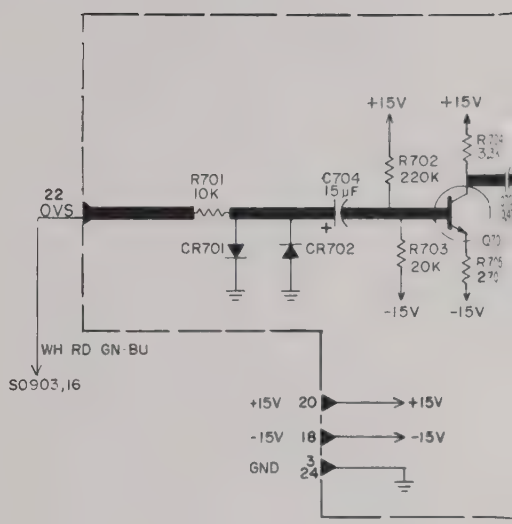


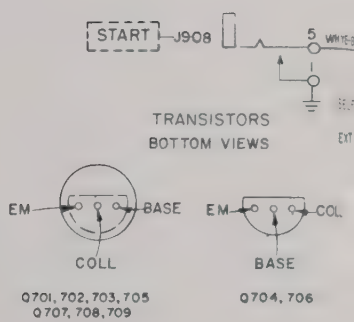
Figure 7-13. Start-circuit etched-board assembly (P/N 1654-4771).

NOTE: The board is shown foil-side up. The number appearing on the foil side is *not* the part number. The dot on the foil at the transistor socket indicates the collector lead.

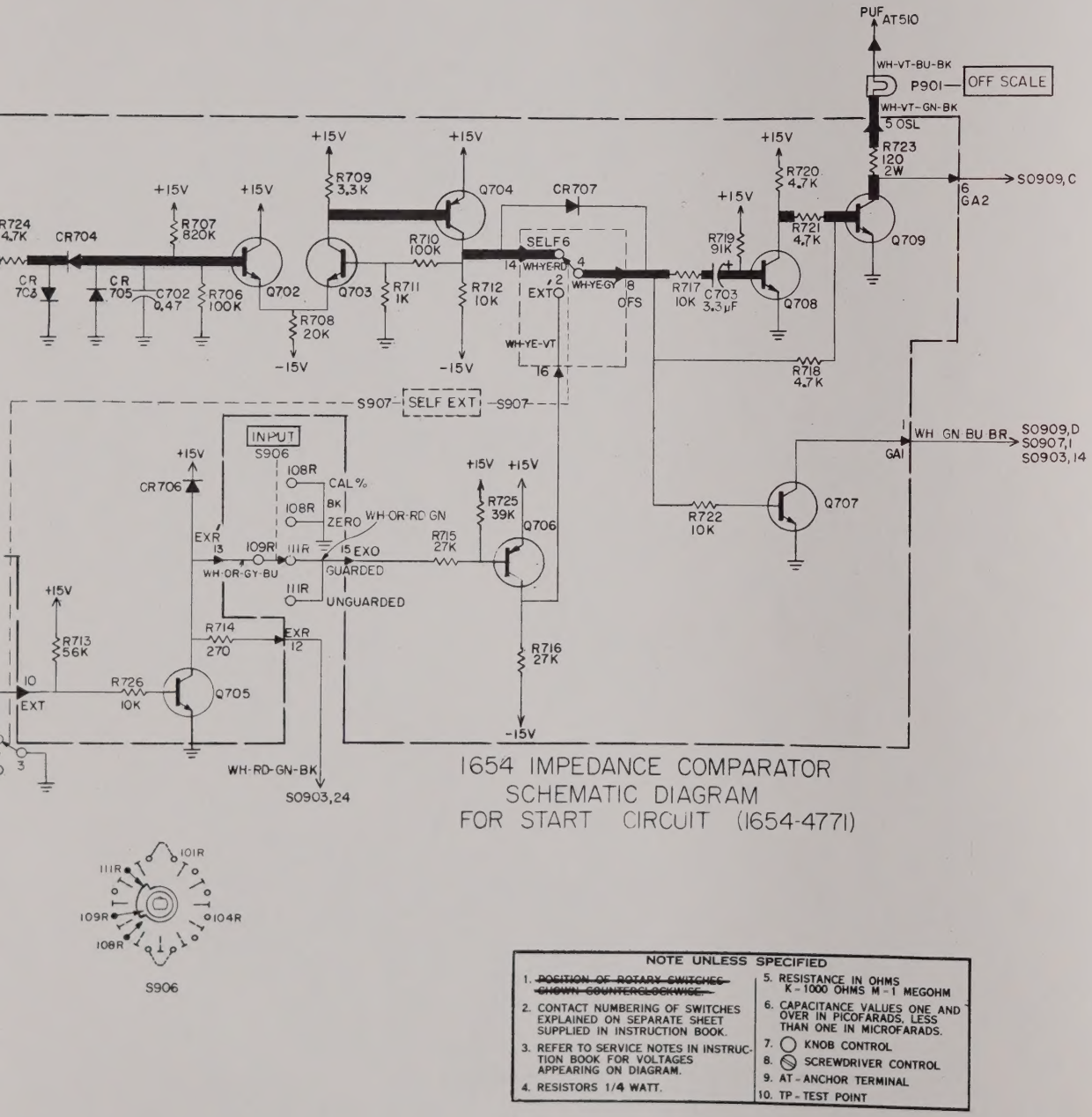
SIGNAL INDEX
START-CIRCUIT ETCHED BOARD
(Reference Figures 7-13 and 7-14)

Signal	Description	Signal Type
GA1	Off-Scale, Relay-Driver Output	dc
GND	Signal Ground	
OSL	Off-Scale, Lamp-Driver Output	dc
GA2	Inhibit Input to 1782 GO Indicator	dc
OFS	Off-Scale Output	dc
EXT	External-Start Input	contact closure
EXR	External-Start, Relay-Driver Output	dc
EXR[1]	External-Start Signal to INPUT Switch	dc
SELF	Self-Start Signal Output	dc
EXO	External-Start Operating Signal	dc
EXT[1]	External-Start Output	dc
–15 V	Power-Supply Voltage	dc
+15 V	Power-Supply Voltage	dc
OVS	Off-Scale Signal Input	rms
GND	Signal Ground	





Rotary switch sections are shown as viewed from the panel end of the shaft. The first digit of the contact number refers to the section. The section nearest the panel is 1, the next section back is 2, etc. The next two digits refer to the contact. Contact 01 is the first position clockwise from a strut screw (usually the screw above the locating key), and the other contacts are numbered sequentially (02, 03, 04, etc), proceeding clockwise around the section. A suffix F or R indicates that the contact is on the front or rear of the section, respectively.



1654 IMPEDANCE COMPARATOR
SCHEMATIC DIAGRAM
FOR START CIRCUIT (1654-4771)

NOTE UNLESS SPECIFIED

1. ~~POSITION OF ROTARY SWITCHES SHOWN COUNTERCLOCKWISE.~~
2. CONTACT NUMBERING OF SWITCHES EXPLAINED ON SEPARATE SHEET SUPPLIED IN INSTRUCTION BOOK.
3. REFER TO SERVICE NOTES IN INSTRUCTION BOOK FOR VOLTAGES APPEARING ON DIAGRAM.
4. RESISTORS 1/4 WATT.
5. RESISTANCE IN OHMS K - 1000 OHMS M - 1 MEGOHM
6. CAPACITANCE VALUES ONE AND OVER IN PICOFARADS, LESS THAN ONE IN MICROFARADS.
7. ◯ KNOB CONTROL
8. ⊘ SCREWDRIVER CONTROL
9. AT - ANCHOR TERMINAL
10. TP - TEST POINT

Figure 7-14. Start circuit schematic diagram.

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